Chapter 2: Costing Methodology

INTRODUCTION

This chapter presents the methodology used to estimate the costs to facilities of complying with the final §316(b) New Facility Rule. This chapter presents detailed information on the development of unit cost estimates for a set of technologies that may be used to meet requirements. This chapter describes how the technology unit costs were used to develop facility-level cost estimates for each projected in-scope facility.

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2.1 BACKGROUND

Facilities using cooling water may be subject to the final §316(b) New Facility Rule. A facility using cooling water can have either a once-through or a recirculating cooling system.

In a once-through system, the cooling water that is drawn in from a waterbody travels through the cooling system once to provide cooling and is then discharged, typically back to the waterbody from which it was withdrawn. The cooling water is withdrawn from a water source, typically a surface waterbody, through a cooling water intake structure (CWIS). Many facilities using cooling water (e.g., steam electric power generation facilities, chemical and allied products manufacturers, pulp and paper plants) need large volumes of cooling water, so the water is generally drawn in through one or more large CWIS, potentially at high velocities. Because of this, debris, tree limbs, and many fish and other aquatic organisms can be drawn toward or into the CWIS. Since a facility's cooling water system can be damaged or clogged by large debris, most facilities have protective devices such as trash racks, fixed screens, or traveling screens, on their CWIS. Some of these devices provide limited protection to fish and other aquatic organisms, but other measures such as the use of passive (e.g., wedgewire) screens, velocity caps, traveling screens with fish baskets, or the use of a recirculating cooling system may provide better protection and have greater capability to minimize adverse environmental impacts.[1]

In a recirculating system, the cooling water is used to cool equipment and steam, absorbing heat in the process, and is then cooled and recirculated to the beginning of the system to be used again for cooling. The heated cooling water is generally cooled in either a cooling tower or in a cooling pond. In the process of being cooled, some of the water evaporates or escapes as steam. Flow lost through evaporation typically ranges from 0.5 percent to 1 percent of the total flow (Antaya, 1999). Also, because of the heating and cooling of recirculating water, mineral deposition occurs which necessitates some bleeding of water from the system. The water that is purged from the system to maintain chemical balance is called blowdown. The amount of blowdown is generally around 1 percent of the flow. Cooling towers may also have a small amount of drift, or windage loss, which occurs when some recirculating water is blown out of the tower by the wind or the velocity of the air flowing through the tower. The water lost to evaporation, blowdown, and drift needs to be replaced by what is typically called makeup water. Overall, makeup water is generally 3 percent or less of the recirculating water flow.[2] Therefore, recirculating systems still need to draw in water and may have cooling water intakes. However, the volume of water drawn in is significantly less than in once-through systems, so the likelihood of adverse environmental impacts as a result of the CWIS is much lower.[3] Also, some recirculating systems obtain their makeup water from ground water sources or public water supplies, and a small but growing number use treated wastewater from municipal wastewater treatment plants for makeup water.

The final §316(b) New Facility Rule establishes a two-track approach for regulating cooling water intake structures at new facilities.[4] Facilities have the opportunity to choose which track (Track I or Track II) they will follow. Facilities choosing to comply with Track I requirements would be required to meet flow reduction, velocity, and design and construction technology requirements. These requirements include reducing cooling water intake flow to a level commensurate with that achievable with a closed-cycle, recirculating cooling system; achieving a through-screen intake velocity of 0.5 feet per second; meeting location- and capacity-based limits on proportional intake flow; and implementing design and construction technologies for minimizing impingement and entrainment and maximizing impingement survival. Facilities choosing to comply with Track II requirements would be required to perform a comprehensive demonstration study to demonstrate that proposed technologies reduce the level of impingement and entrainment to the same level that would be achieved by implementing the requirements of Track I.

2.2 Overview of Costing Methodology

Based on information provided by vendors and industry representatives, EPA first developed unit costs and cost curves, including both capital costs and operations and maintenance (O&M) costs, for a number of primary technologies such as traveling screens and cooling towers that facilities may use to meet requirements under the final §316(b) New Facility Rule. Unit costs are estimated costs of certain activities or actions, expressed on a uniform basis (i.e., using the same units), that a facility may take to meet the regulatory requirements. Unit costs are developed to facilitate comparison of the costs of different actions. For this analysis, the unit basis is dollars per gallon per minute ($/gpm) of flow. For most technologies, EPA used the cooling water intake flow as the basis for unit costs; for cooling towers, EPA used the cooling water recirculating flow through the tower as the basis for unit costs. EPA estimated all capital and operating and maintenance (O&M) costs in these units. These unit costs and cost curves are the building blocks for developing costs at the facility and national levels.

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[1]CWIS devices used in an effort to protect fish also include other fish diversion and avoidance systems (e.g., barrier nets, strobe lights, electric curtains), which may be effective in certain conditions and for certain species. See Chapter 5 of this document.

[2]In some saltwater cooling towers, however, makeup water can be as much as 15 percent.

[3]Manufacturer Brackett Green notes that closed loop systems (i.e., recirculating systems) normally require one-sixth the number of traveling screens as a power plant of equal size that has a once-through cooling system.

[4]See *Economic Analysis of the Final Regulations Addressing Cooling Water Intake Structures for New Facilities* (hereinafter referred to as the *Economic Analysis*), Chapter 1: Introduction and Overview for a summary of this rule's requirements.

While EPA developed unit costs for a number of available technologies, EPA used only a limited set of these technologies to develop facility-level capital and O&M cost estimates. For purposes of cost estimation, EPA assumed that facilities would meet the flow reduction requirement by installing cooling towers. EPA assumed that facilities would meet the velocity and design and construction technology requirements by installing traveling screens with fish handling features, with an intake velocity of 0.5 ft/s.

EPA used unit cost curves to develop facility-level capital and O&M cost estimates for 41 model facilities. These model facilities were then scaled to represent total industry compliance costs for the 121 facilities projected to begin operation between 2001 and 2020. Individual facilities will incur only a subset of the unit costs, depending on the extent to which they would have already complied with the requirements as originally designed (in the baseline) and on the compliance response they select. To account for this, EPA established a number of baseline scenarios (reflecting different baseline cooling water system types and waterbody types) so that the unit costs could be applied to the various model facilities to obtain facility-level costs.

The cost estimates developed for various technologies are intended to represent a National "typical average" cost estimate. The cost estimates should not be used as a project pricing tool as they cannot account for all the site-specific conditions for a particular project.

The facility-level capital and O&M costs presented in this chapter represent the net increase in costs for each set of compliance technology performance requirements as compared to the technology the facility would have installed absent this regulation. To calculate net costs for each model facility, EPA first calculated the cost for the entire cooling system for the baseline technology combination, and then subtracted those costs from the calculated cost of the entire cooling system for each compliance technology combination.

Development of the facility-level capital and O&M costs for the final §316(b) New Facility Rule is discussed in detail in Section 2.3 below. In addition to the facility-level cost estimates developed for the preferred two-track option adopted for the final rule, EPA also developed facility-level cost estimates for several additional options that EPA considered but did not adopt for the final rule. Development of the facility-level capital and O&M cost estimates for these options are also discussed in Section 2.3.

In addition, EPA applied an energy penalty cost to those electric generators switching to recirculating systems to account for performance penalties that may result in reductions of energy or capacity produced because of adoption of recirculating cooling tower systems. These performance penalties are associated with reduced turbine efficiencies due to higher back pressures associated with cooling towers, as well as with power requirements to operate cooling tower pumps and fans. EPA's costing methodology for performance penalties is based on the concept of lost operating revenue due to a mean annual performance penalty. EPA estimated the mean annual performance penalty for recirculating cooling tower systems as compared to once-through cooling systems. EPA then applied this mean annual penalty to the annual revenue estimates for each facility projected to install a recirculating cooling tower technology as a result of the rule. It should be noted that EPA took a conservative approach and double-counted some parts of the energy penalty, since fan and pump power costs were included in both the energy penalty and the cooling tower O&M costs. Energy penalties are discussed in detail in Chapter 3 of this document and their costs are presented in the *Economic Analysis*.

Compliance with the final section §316(b) New Facility Rule also requires facilities to carry out certain administrative functions. These are either one-time requirements (compilation of information for the initial NPDES permit) or recurring requirements (compilation of information for NPDES permit renewal, and monitoring and record keeping), and depend on the facility's water body type and the permitting track the facility follows. Development of these administrative costs is discussed in the *Information Collection Request for Cooling Water Intake Structures, New Facility Final Rule* (referred to as the ICR) and in the *Economic Analysis*.

All costs presented in this chapter are expressed in 1999 dollars. For the *Economic Analysis* for the final §316(b) New Facility Rule, EPA escalated these costs to 2000 dollars.

2.3 Facility Level Costs

2.3.1 General Approach

The facility-level cost estimates presented in this section are based on a limited set of the unit costs presented in detail in the following sections of this Chapter. For purposes of cost estimation, EPA assumed that facilities would meet the flow reduction requirement by switching to recirculating systems. EPA assumed that all planned facilities switching to recirculating systems would use cooling towers (the most common type of recirculating system). This is consistent with the requirement of the final section 316(b) New Facility Rule to reduce intake flow to a level commensurate with that which could be obtained by use of a closed-cycle recirculating system. EPA assumed that facilities would meet the velocity and design and construction technology requirements by installing traveling screens with fish handling features, with an intake velocity of 0.5 ft/s. This is a conservative assumption because such technologies are among the more expensive technologies available for reducing velocity and I&E.

EPA used 41 model facilities to develop facility-level capital and O&M cost estimates for the 121 facilities projected to begin operation between 2001 and 2020. The development of model facilities is described in Chapter 1. Individual facilities subject to the regulation will incur differing costs depending on site specific conditions, technologies projected to be installed in the baseline (i.e., regardless of this regulation), and on the compliance response they select. To account for this, EPA established a number of baseline scenarios (reflecting different baseline cooling water system types and waterbody types) so that the unit costs could be applied to the various model facilities to obtain facility-level costs.

In this analysis, the baseline technology represents an estimation of the technologies that would be constructed at new facilities prior to implementation of the final New Facility Rule regulatory requirements. Specifically, the costs presented in the cost tables represent the net increase in costs for each set of compliance technology/monitoring requirements as compared to the baseline technology. EPA accomplished this by calculating the cost for the entire cooling system for the baseline technology combination and then subtracting those costs from the calculated cost of the entire cooling system for each compliance technology combination.

The final New Facility Rule allows for facilities to comply with one of two alternative sets of permitting requirements (Track 1 and Track 2). Facilities choosing to comply with Track 1 permitting requirements would be required to meet flow reduction, velocity, and design and construction technology requirements. Facilities choosing to comply with Track 2 permitting requirements would be required to perform a comprehensive demonstration study to confirm that proposed technologies reduce the level of impingement and entrainment mortality to the same level that would be achieved by implementing the flow reduction, velocity, and design and construction technology requirements of Track I.

EPA assumed that facilities that were projected to have recirculating baseline cooling water systems would follow Track I. EPA developed cost estimates for these facilities based on the assumption that they would already be installing cooling towers, and thus would only have to install velocity reducing design and construction technologies of traveling screens with fish handling features.

EPA assumed that facilities that were projected to have once-through baseline cooling water systems would follow Track II. EPA developed cost estimates for these facilities based on the assumption that they would perform comprehensive demonstration studies, but would still have to install cooling towers and design and construction technologies of traveling screens with fish return systems to meet the regulatory requirements. This is a conservative assumption that may overestimate compliance costs if a significant number of Track II facilities are able to demonstrate that lower cost alternative technologies will reduce the level of impingement and entrainment to the same level that would be achieved by implementing the flow reduction, velocity, and design and construction technology requirements of Track I.

Some facilities were projected to have mixed once-through and recirculating baseline cooling water systems. EPA treated these facilities the same as facilities with baseline once-through cooling water systems. This represents a conservative approach since it will tend to overestimate the size of the baseline cooling water system that would have to be replaced, and thus overestimate the corresponding compliance cost. In addition, one coal facility was projected to have a recirculating system with a cooling pond. This facility was also costed to switch to a cooling tower.[5]

2.3.2 Capital Costs

Capital cost estimates used in calculating the net compliance costs include individual estimates for the following initial one-time cost components where applicable:

- Once-through system including intake structure, pumps, and piping costs.
- Recirculating wet towers.
- Intake for wet tower make-up water including intake pumps and piping.
- Intake screens.

EPA summed these individual cost elements together to derive the total capital costs for each baseline and compliance scenario. EPA then subtracted the total baseline cost from the total compliance cost to determine the incremental cost of compliance with the final §316(b) New Facility Rule.

EPA concluded that the cooling water flow through the condenser at a given facility to be the same when switching from once-through to wet towers because the design specifications of surface condensers for both types of systems are similar enough that the condenser costs would also be similar. Thus, when comparing wet cooling systems, differences in costs from baseline for the surface condensers were assumed to be zero.

2.3.3 Operation & Maintenance Costs

O&M cost estimates used in calculating the net compliance costs include individual estimates for the following cost components where applicable:

- Operating costs for pumping intake water.
- O&M costs for operating recirculating wet towers.
- O&M cost for operating intake screen technology.
- Annual post-compliance operational monitoring.

EPA summed these individual cost elements together to derive the total O&M costs for each baseline and compliance scenario. EPA then subtracted the total baseline cost from the total compliance cost to determine the incremental cost of compliance with the final §316(b) New Facility Rule.

It should be noted that EPA overcosted the costs of post-compliance operational monitoring, since these costs were also included in the annual administrative costs as described in the ICR and the *Economic Analysis*.

[5]In some states, a cooling pond is considered a water of the U.S. In these states, a plant with such a cooling system would have to comply with the recirculating requirements of the final section 316(b) New Facility Rule. In those states where a cooling pond is not considered a water of the U.S., a plant would not have to comply with the recirculating requirements of this final New Facility Rule. This costing analysis made the conservative assumption that facilities with a cooling pond would have to comply with the recirculating requirements. These facilities were therefore costed as if they had a once-through system in the baseline.

2.3.4 Development of Model Facilities

EPA developed cost estimates for 41 model facilities within three industry categories: coal-fired power plants, combined cycle power plants and manufacturers. These model facilities were developed to reflect a range of potential design intake flows and (for power plants) megawatt (MW) capacities. The methodology for developing model facilities for each of these three industry groups is described in Chapter 1.

2.3.5 Wet Tower Intake Flow Factors

EPA based all model facility flow values, including both intake and cooling water, upon projected intake flows for the baseline technology. When switching from baseline once-through to recirculating wet tower cooling systems, EPA assumed that the recirculating cooling flows through the wet towers would be equivalent to the baseline once-through flows. When either the intake flow or the cooling flow had been projected for wet towers, EPA then calculated the corresponding cooling flow or intake flow using a wet tower make-up water intake flow factor.

EPA used different make-up flow factors for power plants versus manufacturers, as well as for facilities using marine versus freshwater source waters. Since seawater and brackish water in marine cooling water sources have higher dissolved solids (TDS) content than freshwater, the blowdown rate should be higher to avoid the build-up of high TDS in the recirculating water as the cooling water evaporates in the tower. The build-up of high TDS can affect the performance of the cooling system, increase corrosion, and create potential water quality problems for the blowdown discharge. Therefore, the portion of the cooling water that must be removed (blowdown) and replaced is greater for higher TDS source waters. Note that seawater represents the worst-case scenario, but in most cases the intakes within the group of facilities attributed to this water body type will be withdrawing brackish water (i.e., the TDS content will be somewhere between that of seawater and freshwater).

The make-up water must replace all cooling water losses, which include blowdown, evaporation, drift, and other uses. One measure of the blowdown requirement is the "concentration factor," which is the ratio of the concentration of a conservative pollutant, such as TDS, in the blowdown divided by the concentration in the make-up water. For freshwater, the concentration factor can range from 2.0 to 10 (Kaplan 2000) depending on site-specific conditions. For marine sources including brackish and saltwater, the concentration factor can range from 1.5 to 2.0 (Burns and Micheletti 2000).

Cooling Tower Fundamentals (Hensley, 1985) provides a set of equations and default values for estimating the rate of evaporation, drift, and blowdown using the temperature rise (20 ºF) and concentration factor. The make-up volume is the sum of these three components. Input values in this calculation include the concentration factor and the temperature rise. The temperature rise used (20 ºF) is consistent with the design values used throughout the wet tower cost estimation efforts. Since the estimate was for national average values, the default values for estimating evaporation and drift presented in the reference were used. Table 2-1 provides the calculated make-up and blowdown rates as a percentage of the recirculating flow for different concentration factors ranging from 1.1 to 10.0, for a wet tower with a recirculating rate of 100,000 gpm. Note that the selection of the recirculating flow rate is not important, since the output values are percentages which would be the same regardless of the flow rate chosen.

Table 2-1: Make-Up and Blowdown Volumes for Different Wet Tower Concentration Factors

Concentration Factor	Evaporation[a] (gpm)	Drift[b] (gpm)	Blowdown (gpm)	Blowdown (%)	Make-Up (gpm)	Make-Up (%)
1.1	1600	20	15,980	16.0%	17,600	17.6%
1.2	1600	20	7980	8.0%	9600	9.6%
1.25	1600	20	6380	6.4%	8000	8.0%
1.3	1600	20	5313	5.3%	6933	6.9%
1.5	1600	20	3180	3.2%	4800	4.8%
2	1600	20	1580	1.6%	3200	3.2%
3	1600	20	780	0.8%	2400	2.4%
5	1600	20	380	0.4%	2000	2.0%
10	1600	20	158	0.2%	1778	1.8%

Based on methodology presented in *Cooling Tower Fundamentals* (Hensley 1985).
[a]Evaporation = 0.0008 x Range (°F) x Recirculating Flow (gpm)
[b]Drift = 0.0002 x Recirculating flow (gpm)
Range = 20 °F
Recirculating Flow = 100,000 gpm

To be conservative, EPA selected the lower concentration factor for each of the two ranges of literature values (2.0 for freshwater and 1.5 for marine water). Note that a lower concentration factor results in a higher make-up rate. EPA used the equations presented in Hensley 1985 to derive the make-up water rates that correspond to the selected concentration factors of 1.5 and 2.0. This method generated make-up rates of 3.2 percent and 4.8 percent for freshwater and marine water, respectively. These factors were then compared to intake flow and generating capacity values of existing facilities. The resulting estimated cooling water flow rates were somewhat high for the plant generating capacity. To correct for this observation and to account for site variations and other cooling water uses, EPA increased the calculated make-up factors by approximately 50 percent and rounded off, resulting in factors of 5 percent and 8 percent for freshwater and marine water, respectively. These values produced estimated cooling flow values that were consistent with data from power plants with similar generating capacities.

Manufacturers use cooling water for numerous processes, some of which may not be amenable to use of recirculating wet towers or to reuse/recycle. While wet towers are being used as a model for estimating cooling system water reduction technology costs for manufacturers, the aggregate make-up water rates may be greater due to these limitations. In order to account for these potential limitations, EPA set the make-up rates for manufacturers equal to twice the rate for power plants using similar water source types. Thus, the makeup water rates for manufacturers were estimated at 10 percent and 16 percent for freshwater and marine water, respectively.

2.3.6 Baseline Cost Components

EPA selected the baseline technologies based upon the projected type of baseline cooling system and the type of facility. The type of water body affects the costs, but not the selection of technologies. The basic components and assumptions for each baseline technology are described below:

2.3.7 Baseline Once-through Cooling

- The intake is located near shoreline and water is pumped using constant speed pumps through steel pipes to and from a surface condenser and is then discharged back to the water body. The once-through cost estimate includes the intake structure, pumps and piping costs. The development of these costs is described in greater detail below.
- For all types of power plants, baseline intakes are equipped with traveling screens (without fish handling systems) with an intake velocity of 1.0 fps. For manufacturing facilities, intakes are equipped only with trash racks which were assumed to be included in the cost of the intake system. Cost curve charts at the end of this chapter were used to generate the intake screen cost estimates.

2.3.8 Baseline Recirculating Wet Towers

- The cost estimates are for recirculating wet towers with redwood construction and splash fill. This is not the most common construction material for cooling towers, it represents a median cost for cooling tower construction. The wet tower approach was 10 ºF with a temperature rise of 20 ºF. Cost curve Charts presented at the end of the chapter were used to generate the wet tower capital cost estimates.
- O&M costs are based on Scenario 1 described in Section 2.2.2.1, in which make-up water is withdrawn from the surface waterbody and blowdown is treated and discharged. Cost curve charts at the end of this chapter was used to generate the wet tower O&M cost estimates.
- EPA assumed that the make-up water volume would be a proportion of the recirculating flow. A separate cost estimate for an appropriately sized cooling water intake with constant speed pumps was added to serve this purpose. EPA developed intake costs in the same manner as for once-though intakes and included costs for an appropriately sized surface condenser.
- For all types of power plants, baseline intakes are equipped with traveling screens (without fish handling systems) with an intake velocity of 1.0 fps. For manufacturing facilities, intakes are equipped only with trash racks which were assumed to be included in the cost of the intake system. Cost curve charts at the end of this chapter were used to generate the intake screen cost estimates.

2.4 COMPLIANCE COST COMPONENTS

2.4.1 Recirculating Wet Towers

- EPA developed costs for recirculating wet towers as the compliance technology using the same assumptions as for baseline recirculating wet tower costs as described above, with the exception of the intake screen technology and the use of variable speed pumps at the intake. All compliance costs included the cost of traveling screens with fish baskets and fish returns with an intake velocity of 0.5 fps at the intake structure. EPA derived costs for traveling screens with fish baskets and fish returns from cost curve data found at the end of this chapter.
- As described above, the make-up water (intake flow) factors used for power plants were 5 percent for freshwater and 8 percent for marine water.

2.4.2 Reuse/recycle

- Water reuse/recycle technologies at manufacturing facilities are expected to produce reductions in intake water use of a similar degree as recirculating wet towers. However, due to the integrated nature and variable uses of cooling water at manufacturing facilities, EPA did not consider the development of a model technology other than recirculating wet towers to be practical. Since it is possible to use recirculating wet towers as a replacement for once-through cooling at manufacturing facilities, the costs for reuse/recycle technologies were estimated to be similar to the cost of using recirculating wet towers. Therefore, at manufacturing facilities, EPA developed the costs for water reuse/recycle and the water intakes using recirculating wet towers as the model. EPA used the same methodology as described above for recirculating wet towers, with the exception that the make-up factors used for reuse/recycle were set at twice the rate used for power plants (10 percent for freshwater and 16 percent for marine water). The higher rate is intended to account for possible limitations in the degree of water use reduction that may be attained by reuse/recycle.

2.5 Cost Estimation Assumptions and Methodology

The assumptions and cost data sources for each of the technologies is described below.

2.5.1 Once-through Capital Costs

The capital costs for the once-through system includes costs for the following:

- Intake structure
- Pumps, pump well, and pump housing
- Piping to and from the condenser
- Service road to the intake structure adjacent to the cooling water pipes

The maximum cooling flow value used to develop the once-through cost equations was 350,000 gpm. If the model facility flow value exceeded this maximum by 10 percent (i.e., > 385,000 gpm), EPA costed multiple parallel once-through units. Assumptions for each of the cost components are described below:

Intake Structure

- Size equivalent to a box with one side equal to the area needed for a traveling screen with an intake velocity of 1.0 fps. 10 ft were added to the height and the minimum side dimension was 8 ft. An adjacent pump well was also added.
- Concrete thickness of 1.5 ft.
- Excavated volume equal to 2.5 times box and pump well volume.
- Dredged volume equal to 2.5 times box and pump well volume.
- Installation of temporary bulkhead with 20 ft added to width.
- Installation of temporary sheet piling to shore up excavation equal to 1.5 times side area for intake and pump well.
- Area cleared was assumed to be 6 times intake and pump well area.

Service Road

- The service road for the intake was made of 6-inch thick reinforced concrete, and a 12-ft width was assumed. An estimated length of road (which is also the cooling water piping distance) was assigned to different intake volumes. EPA based the lengths on the cooling water flow, since the cooling water flow should be proportional to the plant size and does not change between types of cooling systems. The cooling flow corresponding to a freshwater system was used in the case of wet towers, since it represented the greatest flow. For intake volumes corresponding to a cooling flow of 500 to 10,000 gpm, a 1,000 ft length was assigned, for >10,000 gpm to 100,000 gpm a 1,500 ft length was used, and for >100,000 gpm a length of 2,000 ft was used.

- Area cleared was assumed to be length times 24 ft.

Pumps and Pump Well

- Assumed 3 pumps with each pump sized at 50 percent of design flow (i.e., one pump served as a back-up). Constant speed pumps were used for baseline costs and variable speed pumps were used for compliance costs.
- Pump installation was set equal to 40 percent to 60 percent of pump and motor costs (60 percent at 500 gpm scaled to 40 percent at 350,000 gpm).
- Pump and motor costs were from vendor quotes based on a 50 ft pumping head. Purchase costs were increased by 15 percent to account for taxes, insurance, and freight.
- Pump housing unit cost was estimated at $\$130/ft^2$.
- Pump and pump well area was established using the per pump footprints in Table 2-2 below.

Table 2-2: Assumed Pump Pad and Well Area

Pump Design Flow (gpm)	Footprint (ft)
250	5x5
500	5x5
2,500	7x6
5,000	7x7
25,000	10x10
50,000	11x11
175,000	12x12

Piping to and from the Condenser

- Pipe length in one direction is equal to service road length, which is described above. Total length is twice this distance.
- Pipe diameters were selected to correspond to pipe velocities ranging from 6 fps for smaller diameter (i.e., 6 inch) to 12 fps for larger diameter pipe.
- Pipe unit cost ranged from $5.50 /in. dia - ft length for smaller pipe to $7.50 /in. dia - ft length for larger pipe.

Intake Screens

As described in Section 2.2.2.3 above, EPA developed cost curves for intake screens of varying widths. The cost curves for each screen width covered a range of flow volumes that tended to overlap those with larger and smaller widths. For purposes of estimating intake screen costs, EPA sized the intake screens according to intake flow volumes. Table 2-3 below summarizes the screen width sizes that were selected for each intake flow volume for the given technology and design specification. Note that the maximum flow volume listed is approximately 10 percent greater than the maximum cost curve input value. For intake flow volumes that exceeded this maximum value, multiple parallel screens of the maximum width listed are costed.

Table 2-3: Intake Flow Volume Criteria for Screen Width Selection

Screen Width	Intake Flow for Traveling Screens @ 1.0 fps (gpm)	Intake Flow for Traveling Screens @ 0.5 fps (gpm)
2 - Foot	0 - 10,000	0 - 5,000
5 - Foot	>10,000 - 24,000	>5,000 - 12,000
10 - Foot	>24,000 - 60,000	>12,000 - 30,000
14 - Foot	>60,000 - 220,000	>30,000 - 110,000
Maximum Flow*	220,000	110,000

* Intake volumes above this value were costed for multiple parallel screens using the maximum screen width shown.

Additional Unit Costs

Table 2-4 below summarizes additional unit costs that were used in deriving the capital costs for the items described above.

Table 2-4: Additional Unit Costs

Cost Item	Unit	Cost/Unit	Comment
Foundation Concrete	Cubic Yard	$259	RS Means Cost Works 2001
Structural Concrete	Cubic Yard	$1,125	Based on 16 in column costs- RS Means Cost Works 2001
Excavation	Cubic Yard	$26	RS Means Cost Works 2001
Bulkhead	Linear foot	$254	RS Means Cost Works 2001
Sheet Piling	Square Foot	$15	RS Means Cost Works 2001
Area Clearing	Acre	$2,975	Clear, grub, cut light trees to 6 in.- RS Means Cost Works 2001
Road Paving	Square Yard	$23.30	Concrete pavement 6 in. thick with reinforcement -RS Means Cost Works 2001

Miscellaneous Costs

EPA factored the following miscellaneous costs into the estimated capital costs as a percentage of the total capital cost. Values were selected from the ranges given in Section 2.2.1.2 above:

- Mobilization and demobilization was estimated to be 3 percent.
- Process engineering was estimated to be 10 percent.
- Contractor overhead and profit are included in the unit cost estimates.
- Electrical was estimated to be 10 percent.
- Site work was estimated to be 10 percent.
- Controls were estimated to be 3 percent.
- The contingency cost was estimated at 10 percent.

2.5.2 Once-through O&M

- The O&M costs are estimated using the cooling water intake pumping energy requirements.
- Pumping head was assumed to be 50 ft for all systems.
- Pump and motor efficiency was 70 percent.
- Annual hours of operation was assumed to be 7860.
- Energy cost was estimated at $0.08/KWH. Note that this value is set near the average consumer costs and is higher than the energy cost to the power plant. This overestimation of the unit energy cost is intended to account for other O&M costs, such as for intake cleaning and maintenance and pumping equipment maintenance, that are not included as separate items.

2.5.3 Recirculating Wet Tower Capital Costs

- For wet towers, it is assumed that recirculating (i.e., cooling) flow would be same as baseline once-through flow.
- Capital costs for the recirculating wet tower include costs for all basic tower components, such as structure, foundation, wiring, piping and recirculating pump costs. Wet tower costs are based on cost data for redwood towers with splash fill and an approach of 10 °F taken from chart at the end of this chapter.
- The maximum cooling flow value used to develop the wet tower cost equations (both Capital and O&M) was 204,000 gpm. If the model facility flow value exceeded this maximum by 10 percent (i.e., > 225,000 gpm), EPA costed multiple parallel wet tower units.
- Costs include installing an inlet structure and pumps using the same assumptions as the once-through intake, except they are sized based on the make-up water requirements described above. Similarly, EPA developed the pipe and service road lengths using same method as for once-through intakes except that road and piping length were based on a recirculating flow corresponding to a freshwater system.

2.5.4 Wet Tower O&M Cost

- Wet tower O&M costs have two components; one for the intake and one for the wet tower. EPA took wet tower O&M costs from cost charts at the end of this chapter. Intake O&M costs were based on intake pumping energy requirements in a similar manner as for once-through pumping described above.
- EPA based the intake O&M costs on cooling water intake pumping energy requirements using the same cost assumptions as for the once-through O&M costs. As with the once-through costs, the energy costs were inflated to account for O&M costs in addition to the pumping energy requirements.

2.6 Alternative Regulatory Options

In addition to the preferred two-track option adopted for the final §316(b) New Facility Rule, EPA also developed facility-level cost estimates for several additional options that EPA considered but did not adopt for the final rule. These additional regulatory options include the following:

- Option 1: Technology-Based Performance Requirements for Different Types of Waterbodies. Under this option, only facilities located on marine waterbodies would be required to reduce intake flow commensurate with the level that can be achieved using a closed-cycle recirculating wet cooling system. For all other waterbody types, the only capacity requirements would be proportional flow reduction requirements. In all waterbodies, velocity limits and a requirement to study, select and install design and construction technologies would apply.

- Option 2A: Flow Reduction Commensurate with the Level Achieved by Closed-Cycle Recirculating Wet Cooling Systems. Under this option, all facilities would be required to reduce intake flow commensurate with the level that can be achieved using a closed-cycle recirculating cooling water system, regardless of the type of waterbody from which they withdraw cooling water. In addition, facilities would need to meet velocity limits, comply with proportional flow requirements, and study, select and install design and construction technologies.

- Option 2B: Flow Reduction Commensurate with the Level Achieved by Use of a Dry Cooling System. Under this option, all steam electric power plants would be required to reduce intake flow commensurate with zero or very low-level intake (i.e., dry cooling). Manufacturing facilities would be required to comply with the national requirement of capacity reduction based on closed-cycle recirculating wet cooling. This option does not distinguish between facilities on the basis of the waterbody from which they withdraw cooling water.

- Option 3: Industry Two-Track Option. Under this option, an applicant choosing Track I would install "highly protective" technologies in return for expedited permitting without the need for pre-operational or operational studies in the source waterbody. Such fast-track technologies might include technologies that reduce intake flow to a level commensurate with closed-cycle recirculating wet cooling and that achieve an average approach velocity of no more than 0.5 ft/s, or any technologies that achieve a level of protection from impingement and entrainment within the expected range for a closed-cycle recirculating wet cooling system. Examples of candidate technologies include: (a) wedgewire screens, where there is constant flow, as in rivers; (b) traveling fine mesh screens with a fish return system designed to minimize impingement and entrainment; and (c) aquatic filter barrier systems, at sites where they would not be rendered ineffective by high flows or fouling. Track II would provide an applicant who does not want to commit to any of the above technology options with an opportunity to demonstrate that site-specific characteristics would justify another cooling water intake structure technology, such as once-through cooling.

EPA used the same model facilities and baseline technologies that were used for the preferred two-track option to develop cost estimates for the alternative regulatory options. In general, EPA used the same assumptions as described above when developing cost estimates for the alternative regulatory options. Exceptions are noted below for each of the alternative regulatory options.

2.6.1 Option 1: Technology-Based Performance Requirements for Different Types of Waterbodies

Freshwater Facilities

- Compliance cooling system remains the same as baseline, but with variable speed intake pumps.
- Compliance intake screen technology consists of traveling screens with fish handling features with an intake velocity of 0.5 fps.

Marine Facilities

- Compliance cooling system consists of recirculating wet towers with variable speed intake pumps.
- Compliance intake screen technology consists of traveling screens with fish handling features with an intake velocity of 0.5 fps.

Administrative costs for this option will differ from the preferred two-track option, as noted in the *Economic Analysis*.

2.6.2 Option 2A: Flow Reduction Commensurate with the Level Achieved by Closed-Cycle Recirculating Wet Cooling Systems

Compliance technologies for this option are the same as for the preferred two-track option adopted in the final rule. Therefore, EPA did not develop separate capital and O&M costs for this option. Administrative costs for this option will differ from the administrative costs for the preferred two-track option, as noted in the *Economic Analysis*.

2.6.3 Option 2B: Flow Reduction Commensurate with the Level Achieved by Use of a Dry Cooling System

Power Plants

- Compliance cooling system consists of dry cooling towers (air cooled condensers).
- No surface water intakes are needed.

Manufacturing Facilities

- Compliance cooling system consists of recirculating wet towers with variable speed intake pumps.
- Compliance intake screen technology consists of traveling screens with fish handling features with an intake velocity of 0.5 fps.

Capital Costs

The use of air cooled condensers (dry cooling system) instead of wet cooling involves the substitution of the surface condenser as well as the cold water system. Thus, the cost of surface condensers needs to be included in the baseline capital costs for once-through and wet tower cooling systems for this option. For baseline once-through systems, EPA incorporated the condenser capital costs into the cooling system cost component that includes intake structure, pumps, pipes, etc. For baseline wet towers, EPA incorporated the condenser costs into the intake system cost component that includes intake structure, pumps, pipes, etc. In the case of wet tower intake costs, the cost equation uses the intake flow as the input variable. Since the condenser cost is based on the cooling water flow, EPA developed a separate intake/condenser cost curve for each scenario that uses a different make-up water factor. For the dry cooling compliance systems, EPA included the air cooled condenser cost in the cooling cost.

Wet Cooling Surface Condensers

- EPA obtained equipment costs for condensers sized to handle 12 cooling flow values ranging from 4,650 gpm to 329,333 gpm from a condenser manufacturer (Graham Corporation). Condenser capital costs include an air removal package plus accessories.
- Condenser installation was set equal to 40 percent to 60 percent of condenser equipment costs (60 percent at 500 gpm scaled to 40 percent at 350,000 gpm).

Air Cooled Condensers

- Costs for dry cooling are based on steel towers sized to handle the equivalent heat rejection rate of the replaced cooling water flow. This conversion is factored into the cost formula, which uses the replaced cooling water flow as the input variable. Development of the unit costs and cost curves for dry cooling systems is discussed in Chapter 4 of this document.
- Dry cooling systems do not require water intakes.

O&M Costs

While EPA explicitly included consideration of surface condenser costs in the capital cost estimates where dry cooling systems were involved, EPA did not directly incorporate corresponding costs for operation and maintenance of the surface condensers into the O&M costs. In general, O&M costs for the condensers will involve maintenance only, since the condensers are static and any energy or other consumable material is already considered in other cost components. Some maintenance, including cleaning of fouled tubes and replacement of damaged tubes may be necessary. However, EPA has concluded that such costs are a small portion of baseline operation of a power plant and would be similarly offset with O & M costs of drying cooling condenser tubes.

2.6.4 Option 3: Industry Proposed Two-Track Option

Facilities with Baseline Once-through Cooling

- Compliance cooling system consists of once-through cooling with variable speed intake pumps.
- Compliance intake screen technology consists of wedgewire (passive) screens with an intake velocity of 0.5 fps.

Facilities with Baseline Recirculating Wet Towers

- Compliance cooling system consists of recirculating wet towers with variable speed intake pumps.
- Compliance intake screen technology consists of traveling screens with fish handling features with an intake velocity of 0.5 fps.

Wedgewire (Passive) Screens

- Where applicable, compliance costs included the cost of wedgewire (passive) screens at the intake structure. Intake velocity was 0.5 fps.
- Costs for passive screens were derived from cost curve data presented at the end of this chapter.
- Table 2-5 below summarizes the screen width sizes that were selected for each intake flow volume for the given technology and design specification. Note that the maximum flow volume listed is approximately 10 percent greater than the maximum cost curve input value. For intake flow volumes that exceeded this maximum value, multiple parallel screens of the maximum width listed are costed.

Table 2-5: Intake Flow Volume Criteria for Screen Width Selection

Screen Width	Intake Flow for Wedgewire Screens @ 0.5 fps (gpm)
2 - Foot	0 - 5,000
5 - Foot	>5,000 - 12,000
10 - Foot	>12,000 - 25,000
Maximum Flow*	25,000

* Intake volumes above this value were costed for multiple parallel screens using the maximum screen width shown.

Administrative costs for this option will differ from the administrative costs for the preferred two-track option, as noted in the *Economic Analysis*.

2.7 Summary of Costs by Regulatory Option

2.7.1 Final Rule

Table 2-6 summarizes the baseline, compliance and net technology costs for each model facility for the preferred two-track option adopted for the final rule. These costs are presented in 1999 dollars. For the *Economic Analysis*, EPA escalated these values to 2000 dollars. Note that not all of the manufacturing model facility costs are used in the economic analysis model.

Table 2-6: Baseline, Compliance and Incremental Technology Costs for Model Facilities Preferred Two-Track Option (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
Coal-Fired Power Plants:						
Coal OT/FW-1	$2,310,000	$389,000	$3,766,000	$600,000	$1,456,000	$211,000
Coal OT/FW-2	$9,991,000	$2,522,000	$19,967,000	$3,423,000	$9,976,000	$901,000
Coal OT/FW-3	$33,411,000	$9,280,000	$68,135,000	$12,141,000	$34,724,000	$2,861,000
Coal R/M-1	$25,265,000	$4,396,000	$25,739,000	$4,484,000	$474,000	$88,000
Coal R/FW-1	$5,546,000	$849,000	$5,641,000	$919,000	$95,000	$70,000
Coal R/FW-2	$19,148,000	$3,241,000	$19,365,000	$3,311,000	$217,000	$70,000
Coal R/FW-3	$66,928,000	$11,970,000	$67,698,000	$12,054,000	$770,000	$84,000
Coal RL/FW-1	$11,372,000	$3,219,000	$24,585,000	$4,296,000	$13,213,000	$1,077,000
Combined Cycle Power Plants:						
CC OT/M-1	$15,989,000	$3,673,000	$28,273,000	$4,979,000	$12,284,000	$1,306,000
CC R/M-1	$5,796,000	$890,000	$5,911,000	$971,000	$115,000	$81,000
CC R/M-2	$10,936,000	$1,819,000	$11,133,000	$1,899,000	$197,000	$80,000
CC R/FW-1	$9,650,000	$1,585,000	$9,776,000	$1,655,000	$126,000	$70,000
CC R/FW-2	$10,968,000	$1,831,000	$11,106,000	$1,902,000	$138,000	$71,000
CC R/FW-3	$12,999,000	$2,223,000	$13,157,000	$2,294,000	$158,000	$71,000
Manufacturing Facilities:						
MAN OT/FW-2621	$1,012,000	$141,000	$1,871,000	$281,000	$859,000	$140,000
MAN OT/M-2812	$6,420,000	$1,556,000	$13,717,000	$2,349,000	$7,297,000	$793,000
MAN OT/FW-2812	$2,814,000	$552,000	$5,450,000	$877,000	$2,636,000	$325,000
MAN R/FW-2812	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000
MAN OT/FW-2819	$875,000	$112,000	$1,598,000	$236,000	$723,000	$124,000
MAN R/FW-2819	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/M-2819	$1,094,000	$159,000	$2,117,000	$328,000	$1,023,000	$169,000
MAN OT/FW-2821	$2,419,000	$458,000	$4,639,000	$741,000	$2,220,000	$283,000
MAN R/FW-2821	$7,367,000	$1,175,000	$7,616,000	$1,254,000	$249,000	$79,000
MAN OT/M-2821	$1,172,000	$176,000	$2,277,000	$354,000	$1,105,000	$178,000
MAN OT/FW-2834	$848,000	$106,000	$1,550,000	$228,000	$702,000	$122,000
MAN R/FW-2834	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/FW-2869	$1,440,000	$235,000	$2,713,000	$419,000	$1,273,000	$184,000
MAN OT/M-2869	$1,067,000	$153,000	$2,062,000	$319,000	$995,000	$166,000
MAN R/FW-2869	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000
MAN OT/FW-2873	$1,253,000	$194,000	$2,342,000	$358,000	$1,089,000	$164,000
MAN R/FW-2873	$13,997,000	$2,424,000	$14,435,000	$2,506,000	$4,380,000	$82,000
MAN R/FW-2911	$4,564,000	$683,000	$4,743,000	$758,000	$179,000	$75,000
MAN OT/FW-2911	$3,079,000	$617,000	$5,959,000	$966,000	$2,880,000	$349,000
MAN OT/FW-3312	$3,527,000	$728,000	$6,866,000	$1,123,000	$3,339,000	$395,000

Table 2-6: Baseline, Compliance and Incremental Technology Costs for Model Facilities Preferred Two-Track Option (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
MAN R/FW-3312	$35,922,000	$6,664,000	$39,993,000	$7,000,000	$4,071,000	$336,000
MAN OT/FW-3316	$985,000	$135,000	$1,815,000	$272,000	$830,000	$137,000
MAN R/FW-3316	$6,449,000	$1,012,000	$6,711,000	$1,092,000	$262,000	$80,000
MAN OT/FW-3317	$1,414,000	$229,000	$2,658,000	$410,000	$1,244,000	$181,000
MAN R/FW-3317	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000
MAN OT/FW-3353	$1,306,000	$206,000	$2,445,000	$375,000	$1,139,000	$169,000
MAN R/FW-3353	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000

2.7.2 Option 1: Technology-Based Performance Requirements for Different Types of Waterbodies

Table 2-7 summarizes the baseline, compliance and net technology costs for each model facility for alternative regulatory Option 1. These costs are presented in 1999 dollars. For the *Economic Analysis*, EPA escalated these values to 2000 dollars. Note that not all of the manufacturing model facility costs are used in the economic analysis model.

Table 2-7: Baseline, Compliance and Incremental Technology Costs for Model Facilities Option 1 (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
Coal-Fired Power Plants:						
Coal OT/FW-1	$2,310,000	$389,000	$2,964,000	$470,000	$654,000	$81,000
Coal OT/FW-2	$9,991,000	$2,522,000	$14,110,000	$2,689,000	$4,119,000	$167,000
Coal OT/FW-3	$33,411,000	$9,280,000	$49,121,000	$9,741,000	$15,710,000	$461,000
Coal R/M-1	$25,265,000	$4,396,000	$25,739,000	$4,484,000	$474,000	$88,000
Coal R/FW-1	$5,546,000	$849,000	$5,641,000	$919,000	$95,000	$70,000
Coal R/FW-2	$19,148,000	$3,241,000	$19,365,000	$3,311,000	$217,000	$70,000
Coal R/FW-3	$66,928,000	$11,970,000	$67,698,000	$12,054,000	$770,000	$84,000
Coal RL/FW-1	$11,372,000	$3,219,000	$16,733,000	$3,423,000	$5,361,000	$204,000
Combined Cycle Power Plants:						
CC OT/M-1	$15,989,000	$3,673,000	$28,273,000	$4,979,000	$12,284,000	$1,306,000
CC R/M-1	$5,796,000	$890,000	$5,911,000	$971,000	$115,000	$81,000
CC R/M-2	$10,936,000	$1,819,000	$11,133,000	$1,899,000	$197,000	$80,000
CC R/FW-1	$9,650,000	$1,585,000	$9,776,000	$1,655,000	$126,000	$70,000
CC R/FW-2	$10,968,000	$1,831,000	$11,106,000	$1,902,000	$138,000	$71,000
CC R/FW-3	$12,999,000	$2,223,000	$13,157,000	$2,294,000	$158,000	$71,000
Manufacturing Facilities:						
MAN OT/FW-2621	$1,012,000	$141,000	$1,386,000	$221,000	$374,000	$80,000

Table 2-7: Baseline, Compliance and Incremental Technology Costs for Model Facilities Option 1 (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
MAN OT/M-2812	$6,420,000	$1,556,000	$13,717,000	$2,349,000	$7,297,000	$793,000
MAN OT/FW-2812	$2,814,000	$552,000	$4,058,000	$657,000	$1,244,000	$105,000
MAN R/FW-2812	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000
MAN OT/FW-2819	$875,000	$112,000	$1,193,000	$190,000	$318,000	$78,000
MAN R/FW-2819	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/M-2819	$1,094,000	$159,000	$2,117,000	$328,000	$1,023,000	$169,000
MAN OT/FW-2821	$2,419,000	$458,000	$3,484,000	$558,000	$1,065,000	$100,000
MAN R/FW-2821	$7,367,000	$1,175,000	$7,616,000	$1,254,000	$249,000	$79,000
MAN OT/M-2821	$1,172,000	$176,000	$2,277,000	$354,000	$1,105,000	$178,000
MAN OT/FW-2834	$848,000	$106,000	$1,154,000	$183,000	$306,000	$77,000
MAN R/FW-2834	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/FW-2869	$1,440,000	$235,000	$1,984,000	$320,000	$544,000	$85,000
MAN OT/M-2869	$1,067,000	$153,000	$2,062,000	$319,000	$995,000	$166,000
MAN R/FW-2869	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000
MAN OT/FW-2873	$1,253,000	$194,000	$1,723,000	$277,000	$470,000	$83,000
MAN R/FW-2873	$13,997,000	$2,424,000	$14,435,000	$2,506,000	$438,000	$82,000
MAN R/FW-2911	$4,564,000	$683,000	$4,743,000	$758,000	$179,000	$75,000
MAN OT/FW-2911	$3,079,000	$617,000	$4,448,000	$724,000	$1,369,000	$107,000
MAN OT/FW-3312	$3,527,000	$728,000	$5,122,000	$841,000	$1,595,000	$113,000
MAN R/FW-3312	$38,851,000	$6,898,000	$39,993,000	$7,000,000	$1,142,000	$102,000
MAN OT/FW-3316	$985,000	$135,000	$1,348,000	$215,000	$363,000	$80,000
MAN R/FW-3316	$6,449,000	$1,012,000	$6,674,000	$1,089,000	$225,000	$77,000
MAN OT/FW-3317	$1,414,000	$229,000	$1,947,000	$314,000	$533,000	$85,000
MAN R/FW-3317	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000
MAN OT/FW-3353	$1,306,000	$206,000	$1,798,000	$289,000	$492,000	$83,000
MAN R/FW-3353	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000

2.7.3 Option 2A: Flow Reduction Commensurate with Closed-Cycle recirculating Wet Cooling Systems

Baseline, compliance and incremental technology capital and O&M costs for this option are the same as for the preferred two-track option.

2.7.4 Option 2B: Flow Reduction Commensurate with Dry Cooling Systems

Table 2-8 summarizes the baseline, compliance and net technology costs for each model facility for alternative regulatory Option 2B. These costs are presented in 1999 dollars. For the *Economic Analysis*, EPA escalated these values to 2000 dollars.

Table 2-8: Baseline, Compliance and Incremental Technology Costs for Model Facilities Option 2B (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
Coal-Fired Power Plants:						
Coal OT/FW-1	$3,757,000	$389,000	$9,397,000	$2,363,000	$5,640,000	$1,974,000
Coal OT/FW-2	$17,139,000	$2,522,000	$62,634,000	$11,427,000	$45,495,000	$8,905,000
Coal OT/FW-3	$59,509,000	$9,280,000	$234,182,000	$38,505,000	$174,673,000	$29,225,000
Coal R/M-1	$34,738,000	$4,396,000	$79,792,000	$16,882,000	$45,054,000	$12,486,000
Coal R/FW-1	$7,643,000	$849,000	$14,892,000	$3,669,000	$7,249,000	$2,820,000
Coal R/FW-2	$26,241,000	$3,241,000	$60,315,000	$11,173,000	$34,074,000	$7,932,000
Coal R/FW-3	$94,286,000	$11,970,000	$232,222,000	$38,355,000	$137,936,000	$26,385,000
Coal RL/FW-1	$20,397,000	$3,219,000	$81,323,000	$13,074,000	$60,926,000	$9,855,000
Combined Cycle Power Plants:						
CC OT/M-1	$26,663,000	$3,673,000	$93,582,000	$13,790,000	$66,919,000	$10,117,000
CC R/M-1	$7,933,000	$590,000	$15,277,000	$3,757,000	$7,344,000	$2,867,000
CC R/M-2	$14,985,000	$1,819,000	$32,319,000	$7,177,000	$17,334,000	$5,358,000
CC R/FW-1	$13,298,000	$1,585,000	$28,513,000	$6,486,000	$15,215,000	$4,901,000
CC R/FW-2	$15,137,000	$1,831,000	$33,374,000	$7,362,000	$18,237,000	$5,531,000
CC R/FW-3	$18,025,000	$2,223,000	$41,410,000	$8,677,000	$23,385,000	$6,454,000

Baseline, compliance and incremental technology capital and O&M costs for manufacturing facilities for this option are the same as for the preferred two-track option.

2.7.5 Option 3: Industry Two-Track Option

Table 2-9 summarizes the baseline, compliance and net technology costs for each model facility for alternative regulatory Option 2B. These costs are presented in 1999 dollars. For the *Economic Analysis*, EPA escalated these values to 2000 dollars. Note that not all of the manufacturing model facility costs are used in the economic analysis model.

Table 2-9: Baseline, Compliance and Incremental Technology Costs for Model Facilities Option 3 (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
Coal-Fired Power Plants:						
Coal OT/FW-1	$2,310,000	$389,000	$2,595,000	$440,000	$285,000	$51,000
Coal OT/FW-2	$9,991,000	$2,522,000	$12,178,000	$2,530,000	$2,187,000	$8,000
Coal OT/FW-3	$33,411,000	$9,280,000	$41,751,000	$9,168,000	$8,340,000	$0*
Coal R/M-1	$25,265,000	$4,396,000	$25,739,000	$4,484,000	$474,000	$88,000
Coal R/FW-1	$5,546,000	$849,000	$5,641,000	$919,000	$95,000	$70,000
Coal R/FW-2	$19,148,000	$3,241,000	$19,365,000	$3,311,000	$217,000	$70,000
Coal R/FW-3	$66,928,000	$11,970,000	$67,698,000	$12,054,000	$770,000	$84,000
Coal RL/FW-1	$11,372,000	$3,219,000	$14,247,000	$3,219,000	$2,875,000	$0*
Combined Cycle Power Plants:						
CC OT/M-1	$15,989,000	$3,673,000	$19,289,000	$3,677,000	$3,300,000	$4,000
CC R/M-1	$5,796,000	$890,000	$5,911,000	$971,000	$115,000	$81,000
CC R/M-2	$10,936,000	$1,819,000	$11,133,000	$1,899,000	$197,000	$80,000
CC R/FW-1	$9,650,000	$1,585,000	$9,776,000	$1,655,000	$126,000	$70,000
CC R/FW-2	$10,968,000	$1,831,000	$11,106,000	$1,902,000	$138,000	$71,000
CC R/FW-3	$12,999,000	$2,223,000	$13,157,000	$2,294,000	$158,000	$71,000
Manufacturing Facilities:						
MAN OT/FW-2621	$1,012,000	$141,000	$1,229,000	$206,000	$217,000	$65,000
MAN OT/M-2812	$6,420,000	$1,556,000	$8,632,000	$1,631,000	$2,212,000	$75,000
MAN OT/FW-2812	$2,814,000	$552,000	$3,608,000	$617,000	$794,000	$65,000
MAN R/FW-2812	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000
MAN OT/FW-2819	$875,000	$112,000	$1,059,000	$177,000	$184,000	$65,000
MAN R/FW-2819	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/M-2819	$1,094,000	$159,000	$1,331,000	$234,000	$237,000	$75,000
MAN OT/FW-2821	$2,419,000	$458,000	$3,108,000	$523,000	$689,000	$65,000
MAN R/FW-2821	$7,367,000	$1,175,000	$7,616,000	$1,254,000	$249,000	$79,000
MAN OT/M-2821	$1,172,000	$176,000	$8,632,000	$1,631,000	$2,212,000	$75,000
MAN OT/FW-2834	$848,000	$106,000	$1,025,000	$171,000	$177,000	$65,000
MAN R/FW-2834	$1,572,000	$175,000	$1,655,000	$246,000	$83,000	$71,000
MAN OT/FW-2869	$1,440,000	$235,000	$1,821,000	$300,000	$381,000	$65,000
MAN OT/M-2869	$1,067,000	$153,000	$1,297,000	$228,000	$230,000	$75,000
MAN R/FW-2869	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000

Table 2-9: Baseline, Compliance and Incremental Technology Costs for Model Facilities Option 3 (1999 $)

Model Facility ID	Baseline		Compliance		Incremental	
	Capital	O&M	Capital	O&M	Capital	O&M
MAN OT/FW-2873	$1,253,000	$194,000	$1,528,000	$259,000	$275,000	$65,000
MAN R/FW-2873	$13,997,000	$2,424,000	$14,435,000	$2,506,000	$438,000	$82,000
MAN R/FW-2911	$4,564,000	$683,000	$4,743,000	$758,000	$179,000	$75,000
MAN OT/FW-2911	$3,079,000	$617,000	$3,945,000	$682,000	$866,000	$65,000
MAN OT/FW-3312	$3,527,000	$728,000	$4,577,000	$793,000	$1,050,000	$65,000
MAN R/FW-3312	$38,851,000	$6,898,000	$39,993,000	$7,000,000	$1,142,000	$102,000
MAN OT/FW-3316	$985,000	$135,000	$1,195,000	$200,000	$210,000	$65,000
MAN R/FW-3316	$6,449,000	$1,012,000	$6,674,000	$1,089,000	$225,000	$77,000
MAN OT/FW-3317	$1,414,000	$229,000	$1,787,000	$294,000	$373,000	$65,000
MAN R/FW-3317	$2,589,000	$346,000	$2,713,000	$419,000	$124,000	$73,000
MAN OT/FW-3353	$1,306,000	$206,000	$1,595,000	$271,000	$289,000	$65,000
MAN R/FW-3353	$3,586,000	$515,000	$3,749,000	$590,000	$163,000	$75,000

*For this model facility, O&M costs for wedgewire screens are actually less than the O&M costs for the baseline traveling screens. To be conservative, EPA has set the incremental O&M cost at $0; this does not reflect potential savings to the facility associated with switching intake screen types.

2.8 Technology Unit Costs

2.8.1 General Cost Information

The cost estimates presented in this analysis include both capital costs and operations and maintenance (O&M) costs and are for primary technologies such as traveling screens and cooling towers. Facilities may install these technologies to meet requirements of the final §316(b) New Facility Rule. Cooling tower cost estimates are presented for various types of cooling towers including towers fitted with features such as plume abatement and noise reduction. Estimated costs for traveling screens were developed mainly from cost information provided by vendors. The cost of installing other CWIS technologies such as passive screens and velocity caps are calculated by applying a cost factor based on the cost of traveling screens. All of the base cost estimates are for new sources.

To provide a relative measurement of the differences in cost across technologies, costs need to be developed on a uniform basis. The cost for many of the CWIS and flow reduction technologies depends on many factors, including site-specific conditions, and the relative importance of many of these factors varies from technology to technology. The factor that is most relevant is the total flow. Therefore, EPA selected total flow as the factor on which to base unit costs and thus use for basic cost comparisons. EPA developed cost estimates, in $/gallons per minute (gpm), for most of the technologies for use at a range of different total intake flow volumes. For cooling towers, EPA developed cost estimates for use at a range of different total recirculating flow volumes.

EPA assumed average values or typical situations for the other factors that also impact the cost components. For example, EPA assumed an average debris level and an intake flow velocity of 0.5 feet per second (fps); EPA also used 1.0 fps for cost comparison purposes. EPA separately assessed the cost effect of variations from these average conditions as add-on costs. For instance, if the water being drawn in has a high debris level, this would tend to increase cost by about 20 percent.

EPA determined the specifications for each factor based on a review of information about the characteristics most likely to be encountered at a typical facility withdrawing cooling water. Cost factors used in this analysis and the assumed values/scenarios are listed below in Table 2-10. EPA's unit cost estimates for the selected technologies are based on the information provided by vendors, industry representative, and published documents.

Table 2-10. Basis for Development of Unit Costs

Base Factor for Developing Unit Costs	Assumed Values of Other Factors for Base Costs
Costs were developed for flows of: [1] < 10,000 gpm - 4 flows 10,000 to < 100,000 gpm - 20 flows 100,000 to 200,000 gpm - 4 flows > 200,000 gpm - 1 flow.	Intake flow velocity = 0.5 fps, and 1.0 fps for comparison Amount and type of debris = average/typical Water quality = fresh water Waterbody flow velocity = moderate flow Accessability to intake = average/typical (no dredging needed, use of crane possible)

Cost Elements

Cost estimates of screens include non-metallic fish handling panels, a spray system, a fish trough, housings and transitions, continuous operating features (intermittent operation feature for traveling screens without fish baskets), a drive unit, frame seals, engineering, and installation. EPA separately estimated costs for spray wash pumps, permitting, and pilot studies.

Cooling towers cost estimates are based on unit costs that include all costs associated with the design, construction, and commissioning of a standard fill cooling tower. Costs of cooling towers with various features, building materials, and types are calculated based on cost comparisons with standard cooling towers.

O&M costs were estimated for each type of technology. These costs were estimated, in part, using a percent of capital costs as a basis and considering additional factors.

Potential Add-Ons to Cost

Amount and type of debris = high or need for smaller than typical openings
Depth of waterbody = particularly shallow or deep
Water quality = salt or brackish water (extra cost for non-corrosive material for device and shorter life expectancy/higher replacement cost)
Waterbody flow velocity = stagnant or rapidly moving
Accessability to intake = cost of difficult installation (extra cost for dredging, extra cost for unusual installation due to site-specific conditions)
Existing intake structure = costs associated with retrofit and what existing structure(s) or conditions would cause the extra costs. For example, if an existing structure has an intake flow of 2.0 fps and the intake velocity will be reduced to 0.5 fps with a new device, additional equipment or changes to other equipment/structures of that part of the intake system may increase capital costs (albeit minimally) when compared to installing a new system.

1) Cost estimates were developed for selected flows in each range (e.g., 4 different flows less than 10,000 gpm). 10,000 gpm = 14.4 MGD

The costs estimated for fish protection equipment are linked to both flow rates and intake width and depth. Cooling towers costs are based on the recirculating flow rate, temperature approach (defined later), and the type of cooling tower. Several industry representatives provided information on how they conduct preliminary cost estimates for cooling towers. This is considered to be the "rule of thumb" in costing cooling towers (i.e., $/gallons per minute). Regional variations in costs do exist. However, EPA has based its cost estimates on average flow designs representing model facilities. EPA often used conservative (i.e. high cost) assumptions in order to develop model facility costs that accurately represent average costs applicable to affected facilities across the country. In addition to the costs presented below, cost curves and equations are provided at the end of this chapter. The cost curves and equations can be used to estimate costs for implementing technologies or taking actions for facilities across a range of intake flows. Additional supporting information can be found in *Cost Research and Analysis of Cooling Water Technologies for 316(b) Regulatory Options* (SAIC, 2000).

2.8.2 Flow

EPA determined preliminary intake flow values for the base factor based on data from the ICR (Information Collection Request) for the §316(b) industry questionnaire, a sampling of responses to the §316(b) industry screener questionnaire, a Utility Data Institute database (UDI, 1995), and industry brochures and technology background papers.[6] Data from these sources represent utility and nonutility steam electric facilities and industrial facilities that could be subject to prospective §316(b) requirements and are provided in Table 2-11. EPA used these data to determine the range of typical intake flows for these types of facilities to ensure that the flows included in the cost estimates were representative. Through data provided by equipment vendors, EPA determined the flows typically handled by available CWIS equipment and cooling towers. Facilities with greater flows would generally either use multiple screens, towers, or other technologies, or use a special design. Considering this information together, EPA selected flows for various screen sizes, water depths, and intake velocities for use in collecting cost data directly from industry representatives.

Table 2-11. Flow Data for Unit Costs

ICR (average intake flows by utility/industry category)

Steam electric utilities:	178 MGD (124,000 gpm) for 1,093 facilities
Steam electric non-utilities:	2.8 MGD (1,944 gpm) for 1,158 facilities
Chemicals & allied products:	0.339 MGD (235 gpm) for 22,579 facilities
Primary metals:	0.327 MGD (227 gpm) for 10,999 facilities
Petroleum & coal products:	0.461 MGD (320 gpm) for 3,509 facilities
Paper & allied products:	0.148 MGD (103 gpm) for 9,881 facilities

UDI Database (design intake flow for steam electric utilities) (UDI, 1995)

Up to 11,219 gpm (16.15 MGD)	401 units
11,220-44,877 gpm (16.16-64.62 MGD)	465 units
44,878-134,630 gpm (64.63-193.9 MGD)	684 units
134,631-448,766 gpm (194-646.2 MGD)	453 units
More than 448,766 gpm (646.2 MGD)	68 units

Sampling of Responses from Industry Screener Questionnaire (daily intake flow for non-utilities)

Up to 0.5 MGD (347 gpm)	6 facilities	>20-30.0 MGD (13,890-20,833 gpm)	2 facilities
>0.5-1.0 MGD (348-694 gpm)	1 facilities	>30-40.0 MGD (20,834-27,778 gpm)	2 facilities
>1-5.0 MGD (695-3,472 gpm)	3 facilities	>40-50.0 MGD (27,779-34,722 gpm)	1 facility
>5.0-10.0 MGD (3,473-6,944 gpm)	8 facilities	>50-100.0 MGD (34,723-69,444 gpm)	0 facilities
>10-20.0 MGD (6,945-13,889 gpm)	2 facilities	>100 MGD (>69,444 gpm)	1 facility

US Filter/Johnson Screens Brochure (ranges for flow definitions) (US Filter, 1998)

Low flow:	200 to 4,000 gpm (0.288 to 5.76 MGD)
Intermediate flow:	1,500 to 15,000 gpm (2.16 to 21.6 MGD)
High flow:	5,000 to 30,000 gpm (7.2 to 43.2 MGD)

Background Technology Papers (SAIC, 1994; SAIC, 1996)

"Relatively low intake flow":	1-30 MGD (694-20,833 gpm)
"Relatively small quantities of water":	up to 50,000 gpm (70 MGD)

[6] EPA sent the *Industry Screener Questionnaire: Phase I Cooling Water Intake Structures* to about 2,500 steam electric non-utility power producers and manufacturers. This sample included most of the non-utility power producers that were identified by EPA and a subset of the identified manufacturers in industry groups that EPA determined use relatively large quantities of cooling water.

2.8.3 Additional Cost Considerations Included in the Analysis

The cost estimates include costs, such as design/engineering, process equipment, and installation, that are clearly part of getting a CWIS structure or cooling tower in place and operational. However, there are additional associated capital costs that may be less apparent but may also be incurred by a facility and have been included in the cost estimates either as stand-alone cost items or included in installation and construction costs. EPA included the following costs as part of the unit cost estimates:

- Mobilization and demobilization,
- Architectural fees,
- Contractor's overhead and profit,
- Process engineering,
- Sitework and yard piping,
- Standby power,
- Electrical allowance,
- Instrumentation and controls, and
- Contingencies
- Installation.

Following is a brief description of these miscellaneous capital cost items to provide an indication of their general effect on capital costs. These descriptions are also intended to help economists adjust costs to account for regional variations within the U.S. EPA notes that for the costs of cooling towers, each of these items is included the total installed capital costs estimates, but these specific items are not necessarily itemized due to EPA's use of a total inclusive cost per gallon estimate for cooling towers.

Mobilization and Demobilization

Mobilization and demobilization costs are costs incurred by the contractor to assemble crews and equipment on-site and to dismantle semi-permanent and temporary construction facilities once the job is completed. The equipment that may be needed includes backhoes, bulldozers, front-end loaders, self-propelled scrapers, pavers, pavement rollers, sheeps-foot rollers, rubber tire rollers, cranes, temporary generators, trucks (including water and fuel trucks), and trailers. Mobilization costs also include bonds and insurance. To account for mobilization and demobilization costs, a range of 2 percent to 5 percent is was added to the total capital cost, depending on the specific site characteristics.

Architectural Fees

Estimates need to include the cost of the building design, architectural drawings, building construction supervision, construction engineering, and travel, not to exceed 8 percent of the capital cost.

Contractor's Overhead and Profit

This element includes field supervision, main office expenses, tools and minor equipment, workers' compensation and employer's liability, field office expenses, performance and payment bonds, unemployment tax, profit, Social Security and Medicare, builder's risk insurance, and public liability insurance. This was estimated at 12 percent of the capital cost.

Process Engineering

Costs for this category include treatment process engineering, unit operation construction supervision, travel, system start-up engineering, study, design, operation and maintenance (O&M) manuals, and record drawings. These costs were estimated by adding a range of 10 percent to 20 percent to the estimated capital cost.

Sitework and Yard Piping

Cost estimates for sitework include site preparation, excavation, backfilling, roads, walls, landscaping, parking lots, fencing, storm water control, yard structures, and yard piping (interconnecting piping between treatment units). These costs were estimated by adding a range of 5 percent to 15 percent to the estimated capital cost for sitework and a range of 3 percent to 7 percent for yard piping.

For installation of CWIS technologies (e.g., screens), a yard piping cost of 5 percent of the total capital cost is sometimes used based on site-specific conditions. Cooling towers require a significant amount of piping (for both new facilities and retrofits to existing facilities) and these costs are already included in the capital cost estimate for cooling towers so an additional 5 percent was not applied.

Standby Power

Standby generators may be needed to produce power to the treatment and distribution system during power outages and should be included in cost estimates. These costs are estimated by adding a range of 2 percent to 5 percent to the estimated construction cost.

Electrical Allowance (including yard wiring)

An electrical allowance should be made for electric wiring, motors, duct banks, MCCs, relays, lighting, etc. These costs are estimated by adding a range of 10 percent to 15 percent to the estimated construction cost.

Instrumentation and Controls

Instrumentation and control (I&C) costs may include a facility control system, software, etc. The cost depends on the degree of automation desired for the entire facility. These costs are estimated by adding a range of 3 percent to 8 percent to the estimated construction cost.

Contingencies

Contingency cost estimates include compensation for uncertainty within the scope of labor, materials, equipment, and construction specifications. This uncertainty factor is estimated to range from 5 percent to 25 percent of all capital costs, with an average of 10 percent for general engineering projects.

Contingency costs can range from 2 percent to 20 percent for construction projects. CWIS technology projects are not typical construction projects since most of the construction is done at the manufacturing facility and site work mainly involves installation. So some of the uncertainties that could occur in typical construction projects are less likely in CWIS projects. Design and manufacture of the technology can be around 90 percent of the total cost for a project that involves a straightforward installation (e.g., no dredging). The approach used in this cost estimate is conservative and is considered to cover contingencies for typical CWIS technology or cooling tower projects.

In its 1992 study of cooling tower retrofit costs, Stone and Webster (1992) included, in its line item costs, an allowance for indeterminates (e.g., contingencies) of 15 percent for future utility projects. The Stone and Webster study involved major retrofit work on existing plants (i.e., converting a once through cooling system plant to recirculating), so the contingencies allowance fell in the higher end of the typical range.

Installation costs

Installation costs are estimated at 80 percent of cooling tower equipment cost based on information provided by equipment vendors. See the end of this chapter for cost curves and equations.

2.8.4 Replacement Costs

Cooling towers may require replacement of equipment during the financing period that is necessary for the upkeep of the cooling tower. These costs tend to increase over the useful life of the tower and constitute an O&M expenditure that needs to be accounted for. Therefore, EPA factored these periodic equipment replacement costs into the O&M cost estimates presented herein. However, EPA has not included the replacement costs for other equipment because the life expectancy is generally expected to last over the financial life of the facility.

2.9 Specific Cost Information for Technologies and Actions

The following sections present information on potential compliance actions that a facility might take, including the installation of certain technologies, in order to meet requirements under the §316(b) New Facility Rule. The information presented includes the cost curves and unit costs developed for each potential compliance action. Estimated costs are presented in 1999 dollars. The cost equations and cost curves can be used to estimate costs. The equations and cost curves generally use flow as the basis for determining estimated costs (i.e., unit costs are in $/gpm). For screens, since flow is dependent on the flow velocity through the screen, different equations and cost curves are included for the two velocities of 0.5 fps and 1.0 fps.

2.9.1 Reducing Design Intake Flow

Switching to a recirculating system

As noted earlier, in a recirculating system cooling water is used to cool equipment and steam, and absorbs heat in the process. The cooling water is then cooled and recirculated to the beginning of the system to be used again for cooling. Recirculating the cooling water in a system vastly reduces the amount of cooling water needed. The method most frequently used to cool the water in a recirculating system is putting the cooling water through a cooling tower. Therefore, EPA chose to cost cooling towers as the technology used to switch a once-through cooling system to a recirculating system.

The factors that generally have the greatest impact on cost are the flow, approach (the difference between cold water temperature and ambient wet bulb temperature), tower type, and environmental considerations. Physical site conditions (e.g., topographic conditions, soils and underground conditions, water quality) affect cost, but in most situations are secondary to the primary cost factors. Table 2-12 presents relative capital and operation cost estimates for various cooling towers in comparison to the conventional, basic Douglas Fir cooling tower as a standard. EPA notes that based on its data collection for recent cooling tower projects, for most cases, environmental considerations such as plume abatement and noise abatement are rarely installed. Therefore, EPA is presenting costs in the following sections for comparison purposes only and these types of costs are not uniformly applicable to a national rule.

Table 2-12. Relative Cost Factors for Various Cooling Tower Types[1]

Tower Type	Capital Cost Factor (%)	Operation Cost Factor (%)
Douglas Fir	100	100
Redwood	112[2]	100
Concrete	140	90
Steel	135	98
Fiberglass Reinforced Plastic	110	98
Splash Fill	120	150

Table 2-12. Relative Cost Factors for Various Cooling Tower Types[1]

Non-Fouling Film Fill	110	102
Mechanical draft	100	100
Natural draft (concrete)	175	35
Hybrid [Plume abatement (32DBT)]	250-300	125-150
Dry/wet	375	175
Air condenser (steel)	250-325	175-225
Noise reduction (10dBA)	130	107

1) Percent estimates are relative to the Douglas Fir cooling tower.
2) Redwood cooling tower costs may be higher because redwood trees are a protected species, particularly in the Northwest.

Sources: Mirsky et al. (1992), Mirsky and Bauthier (1997), and Mirsky (2000).

There are two general types of cooling towers, wet and dry. Wet cooling towers, which are the far more common type, reduce the temperature of the water by bringing it directly into contact with large amounts of air. Through this process, heat is transferred from the water to the air which is then discharged into the atmosphere. Part of the water evaporates through this process thereby having a cooling effect on the rest of the water. This water then exits the cooling tower at a temperature approaching the wet bulb temperature of the air.

For dry cooling towers, the water does not come in direct contact with the air, but instead travels in closed pipes through the tower. Air going through the tower flows along the outside of the pipe walls and absorbs heat from the pipe walls which absorb heat from the water in the pipes. Dry cooling towers tend to be much larger and more costly than wet towers because the dry cooling process is less efficient. Also, the effluent water temperature is warmer because it only approaches the dry bulb temperature of the air (not the cooler wet bulb temperature). Development of unit costs and cost curves for dry cooling towers is discussed in Chapter 4 of this document.

Hybrid wet-dry towers, which combine dry heat exchange surfaces with standard wet cooling towers, are plume abatement towers. These towers tend to be used most where plume abatement is required by local authorities. Technologies for achieving low noise and low drift can be fitted to all types of towers.

Other characteristics of cooling towers include:

- ***Air flow*****:** Mechanical draft towers use fans to induce air flow, while natural draft (i.e., hyperbolic) towers induce natural air flow by the chimney effect produced by the height and shape of the tower. For towers of similar capacity, natural draft towers typically require significantly less land area and have lower power costs (i.e., fans to induce air flow are not needed) but have higher initial costs (particularly because they need to be taller) than mechanical draft towers. Both mechanical draft and natural draft towers can be designed for air to flow through the fill material using either a crossflow (air flows horizontally) or counterflow (air flows vertically upward) design, while the water flows vertically downward. Counterflow towers tend to be more efficient at achieving heat reduction but are generally more expensive to build and operate because clearance needed at the bottom of the tower means the tower needs to be taller.

- ***Mode of operation*****:** Cooling towers can be either recirculating (water is returned to the condenser for reuse) or non-recirculating (tower effluent is discharged to a receiving waterbody and not reused). Facilities using non-recirculating types (i.e., "helper" towers) draw large flows for cooling and therefore do not provide fish protection for §316(b) purposes, so the information in this chapter is not intended to address non-recirculating towers.

- ***Construction materials*:** Towers can be made from concrete, steel, wood, and/or fiberglass.

Generally, all cooling towers with plume abatement features are hybrid towers. According to the Standard Handbook of Power Plant Design, attempts to modify towers with special designs and construction features to abate plumes has been tested but not accepted as an effective technology. Natural draft towers are concrete towers, although some old natural draft wood cooling towers do exist. Therefore, for costing purposes, concrete is assumed to be the material used for building natural draft cooling towers.

Capital Cost of Cooling Towers

Typically, the cost of the project is determined based on the following factors: type of equipment to be cooled (e.g., coal fired equipment, natural gas powered equipment); location of the water intake (on a river, lake, or seashore); amount of power to-be-generated (e.g., 50 Megawatt vs. 200 Megawatt); and volume of water needed. The volume of water needed for cooling depends on the following critical parameters: water temperature, make of equipment to be used (e.g, G.E turbine vs. ABB turbine, turbine with heat recovery system and turbine without heat recovery system), discharge permit limits, water quality (particularly for wet cooling towers), and type of wet cooling tower (i.e., whether it is a natural draft or a mechanical draft).

Two cooling tower industry managers with extensive experience in selling and installing cooling towers to power plants and other industries provided information on how they estimate budget capital costs associated with a wet cooling tower. The rule of thumb they use is $30/gpm for a delta of 10 degrees and $50/gpm for a delta of 5 degrees.[7] This cost is for a "small" tower (flow less than 10,000 gpm) and equipment associated with the "basic" tower, and does not include installation. Ancillary costs are included in the installation factor estimate listed below. Above 10,000 gpm, to account for economy of scale, the unit cost was lowered by $5/gpm over the flow range up to 204,000 gpm. For flows greater than 204,000 gpm, a facility may need to use multiple towers or a custom design. Combining this with the variability in cost among various cooling tower types, costs for various tower types and features were calculated for the flows used in calculating screen capacities at 1 ft/sec and 0.5 ft/sec.

To estimate costs specifically for installing and operating a particular cooling tower, important factors include:

- ***Condenser heat load and wet bulb temperature (or approach to wet bulb temperature)*:** Largely determine the size needed. Size is also affected by climate conditions.

- ***Plant fuel type and age/efficiency*:** Condenser discharge heat load per Megawatt varies greatly by plant type (nuclear thermal efficiency is about 33 percent to 35 percent, while newer oil-fired plants can have nearly 40 percent thermal efficiency, and newer coal-fired plants can have nearly 38 percent thermal efficiency).[8] Older plants typically have lower thermal efficiency than new plants.

- ***Topography*:** May affect tower height and/or shape, and may increase construction costs due to subsurface conditions. For example, sites requiring significant blasting, use of piles, or a remote tower location will typically have greater installation/construction cost.

- ***Material used for tower construction*:** Wood towers tend to be the least expensive, followed by fiberglass reinforced plastic, steel, and concrete. However, some industry sources claim that Redwood capital costs might be much higher compared to

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[7]The delta is the difference between the cold water (tower effluent) temperature and the tower wet bulb temperature. This is also referred to as the design approach. For example, at design conditions with a delta or design approach of 5 degrees, the tower effluent and blowdown would be 5 degrees warmer than the wet bulb temperature. A smaller delta (or lower tower effluent temperature) requires a larger cooling tower and thus is more expensive.

[8]With a 33 percent efficiency, one-third of the heat is converted to electric energy and two-thirds goes to waste heat in the cooling water.

other wood cooling towers, particularly in the Northwest U.S., because Redwood trees are a protected species. Factors that affect the material used include chemical and mineral composition of the cooling water, cost, aesthetics, and local/regional availability of materials.

C **_Pollution control requirements_:** Air pollution control facilities require electricity to operate. Local requirements to control drift, plume, fog, and noise and to consider aesthetics can also increase costs for a given site (e.g., different design specifications may be required).

Summaries of some EPRI research on dry cooling systems and wet-dry supplemental cooling systems note that dry cooling towers may cost as much as four times more than conventional wet towers (EPRI, 1986a and 1986b).

Table 2-13: Estimated Capital Costs of Cooling Towers without Special Environmental Impact Mitigation Features (1999 Dollars)

Flow (gpm)	Basic Douglas Fir Cooling Tower Cost[1]	Redwood Tower	Concrete Tower	Steel Tower	Fiberglass Reinforced Plastic Tower
2000	$108,000	$121,000	$151,000	$146,000	$119,000
4000	$216,000	$242,000	$302,000	$ 292,000	$238,000
7000	$378,000	$423,000	$529,000	$ 510,000	$416,000
9000	$486,000	$544,000	$680,000	$ 656,000	$535,000
11,000	$594,000	$665,000	$832,000	$ 802,000	$653,000
13,000	$702,000	$786,000	$983,000	$ 948,000	$772,000
15,000	$810,000	$907,000	$1,134,000	$1,094,000	$891,000
17,000	$918,000	$1,028,000	$1,285,000	$1,239,000	$1,010,000
18,000	$972,000	$1,089,000	$1,361,000	$1,312,000	$1,069,000
22,000	$1,148,400	$1,286,000	$1,608,000	$1,550,000	$1,263,000
25,000	$1,305,000	$1,462,000	$1,827,000	$1,762,000	$1,436,000
28,000	$1,461,600	$1,637,000	$2,046,000	$1,973,000	$1,608,000
29,000	$1,513,800	$1,695,000	$2,119,000	$2,044,000	$1,665,000
31,000	$1,618,200	$1,812,000	$2,265,000	$2,185,000	$1,780,000
34,000	$1,774,800	$1,988,000	$2,485,000	$2,396,000	$1,952,000
36,000	$1,879,200	$2,105,000	$2,631,000	$2,537,000	$2,067,000
45,000	$2,268,000	$2,540,000	$3,175,000	$3,062,000	$2,495,000
47,000	$2,368,800	$2,653,000	$3,316,000	$3,198,000	$2,606,000
56,000	$2,822,400	$3,161,000	$3,951,000	$3,810,000	$3,105,000
63,000	$3,175,200	$3,556,000	$4,445,000	$4,287,000	$3,493,000
67,000	$3,376,800	$3,782,000	$4,728,000	$4,559,000	$3,714,000
73,000	$3,679,200	$4,121,000	$5,151,000	$4,967,000	$4,047,000
79,000	$3,839,400	$4,300,000	$5,375,000	$5,183,000	$4,223,000
94,000	$4,568,400	$5,117,000	$6,396,000	$6,167,000	$5,025,000
102,000	$4,957,200	$5,552,000	$6,940,000	$6,692,000	$5,453,000
112,000	$5,443,200	$6,096,000	$7,620,000	$7,348,000	$5,988,000
146,000	$7,095,600	$7,947,000	$9,934,000	$9,579,000	$7,805,000
157,000	$7,347,600	$8,229,000	$10,287,000	$9,919,000	$8,082,000
204,000	$9,180,000	$10,282,000	$12,852,000	$12,393,000	$10,098,000

1) Includes installation at 80 percent of equipment cost for a delta of 10 degrees.

Using the estimated costs, EPA developed cost equations using a polynomial curve fitting function. Table 2-14 presents cost equations for basic tower types built with different building materials and assuming a delta of 10 degrees. The cost equations presented in Table 2-13 include installation costs. The "x" in the presented cost equations is for flow in gpm and the "y" is in dollars.

Table 2-14. Capital Cost Equations of Cooling Towers without Special Environmental Impact Mitigation Features (Delta 10 degrees)

Tower Type	Capital Cost Equation[1]	Correlation Coefficient
Douglas Fir	$y = -9E\text{-}11x^3 - 8E\text{-}06x^2 + 50.395x + 44058$	$R^2 = 0.9997$
Redwood	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 56.453x + 49125$	$R^2 = 0.9997$
Steel	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 68.039x + 59511$	$R^2 = 0.9997$
Concrete	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 70.552x + 61609$	$R^2 = 0.9997$
Fiberglass Reinforced Plastic	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 55.432x + 48575$	$R^2 = 0.9997$

1) x is for flow in gpm and y is cost in dollars.

Using the cost comparison information published by Mirsky et al. (1992), EPA calculated the costs of cooling towers with various additional features. These costs are presented in Table 2-15. Table 2-15 presents capital costs of the Douglas Fir Tower with various features. The costs for other types of cooling towers were calculated in a similar manner.

Table 2-16 presents cost equations for Douglas fir cooling towers with special environmental mitigation features, built with different building materials and assuming a delta of 10 degrees. The cost equations presented in Table 2-16 include installation costs. The "x" in the presented cost equations is for flow in gpm and the "y" is in dollars. The final costs were based on cost curves constructed for redwood splash fill towers. Costs and cost equations for Douglas fir towers are listed here as an example of how cost equation curves were developed, although these are not the costs used to develop the facility costs.

At the end of this chapter, cost curves with equations are also presented for other types of cooling towers.

Table 2-15: Capital Costs of Douglas Fir Cooling Towers with Special Environmental Impact Mitigation Features (Delta 10 degrees) (1999 Dollars)

Flow (gpm)	Douglas Fir Cooling Tower	Splash Fill	Non-fouling Film Fill	Noise Reduction 10 dBA	Dry/wet	Hybrid Tower (32DBT Plume Abatement)
2000	$108,000	$130,000	$119,000	$140,000	$405,000	$324,000
4000	$216,000	$259,000	$238,000	$281,000	$810,000	$648,000
7000	$378,000	$454,000	$416,000	$491,000	$1,418,000	$1,134,000
9000	$486,000	$583,000	$535,000	$632,000	$1,823,000	$1,458,000
11,000	$594,000	$713,000	$653,000	$772,000	$2,228,000	$1,782,000
13,000	$702,000	$842,000	$772,000	$913,000	$2,633,000	$2,106,000
15,000	$810,000	$972,000	$891,000	$1,053,000	$3,038,000	$2,430,000
17,000	$918,000	$1,102,000	$1,010,000	$1,193,000	$3,443,000	$2,754,000
18,000	$972,000	$1,166,000	$1,069,000	$1,264,000	$3,645,000	$2,916,000
22,000	$1,148,400	$1,378,000	$1,263,000	$1,493,000	$4,307,000	$3,445,000
25,000	$1,305,000	$1,566,000	$1,436,000	$1,697,000	$4,894,000	$3,915,000
28,000	$1,461,600	$1,754,000	$1,608,000	$1,900,000	$5,481,000	$4,385,000
29,000	$1,513,800	$1,817,000	$1,665,000	$1,968,000	$5,677,000	$4,541,000
31,000	$1,618,200	$1,942,000	$1,780,000	$2,104,000	$6,068,000	$4,855,000
34,000	$1,774,800	$2,130,000	$1,952,000	$2,307,000	$6,656,000	$5,324,000
36,000	$1,879,200	$2,255,000	$2,067,000	$2,443,000	$7,047,000	$5,638,000
45,000	$2,268,000	$2,722,000	$2,495,000	$2,948,000	$8,505,000	$6,804,000
47,000	$2,368,800	$2,843,000	$2,606,000	$3,079,000	$8,883,000	$7,106,000
56,000	$2,822,400	$3,387,000	$3,105,000	$3,669,000	$10,584,000	$8,467,000
63,000	$3,175,200	$3,810,000	$3,493,000	$4,128,000	$11,907,000	$9,526,000
67,000	$3,376,800	$4,052,000	$3,714,000	$4,390,000	$12,663,000	$10,130,000
73,000	$3,679,200	$4,415,000	$4,047,000	$4,783,000	$13,797,000	$11,038,000
79,000	$3,839,400	$4,607,000	$4,223,000	$4,991,000	$14,398,000	$11,518,000
94,000	$4,568,400	$5,482,000	$5,025,000	$5,939,000	$17,132,000	$13,705,000
102,000	$4,957,200	$5,949,000	$5,453,000	$6,444,000	$18,590,000	$14,872,000
112,000	$5,443,200	$6,532,000	$5,988,000	$7,076,000	$20,412,000	$16,330,000
146,000	$7,095,600	$8,515,000	$7,805,000	$9,224,000	$26,609,000	$21,287,000
157,000	$7,347,600	$8,817,000	$8,082,000	$9,552,000	$27,554,000	$22,043,000
204,000	$9,180,000	$11,016,000	$10,098,000	$11,934,000	$34,425,000	$27,540,000

Table 2-16. Capital Cost Equations of Douglas Fir Cooling Towers with Special Environmental Impact Mitigation Features (Delta 10 degrees)

Tower Type	Capital Cost Equation[1]	Correlation Coefficient
Douglas Fir	$y = -9E\text{-}11x^3 - 8E\text{-}06x^2 + 50.395x + 44058$	$R^2 = 0.9997$
Splash Fill	$y = -4E\text{-}05x^2 + 62.744x + 22836$	$R^2 = 0.9996$
Non-fouling Film Fill	$y = -1E\text{-}10x^3 - 9E\text{-}06x^2 + 55.432x + 48575$	$R^2 = 0.9997$
Noise Reduction 10 dBA	$y = -1E\text{-}10x^3 - 1E\text{-}05x^2 + 65.517x + 57246$	$R^2 = 0.9997$
Dry/Wet	$y = -0.0001x^2 + 196.07x + 71424$	$R^2 = 0.9996$
Hybrid Tower (Plume Abatement 32DBT)	$y = -3E\text{-}10x^3 - 2E\text{-}05x^2 + 151.18x + 132225$	$R^2 = 0.9997$

1) x is flow in gpm and y is cost in dollars.

Validation of Cooling Tower Capital Cost Equations

To validate the cooling tower capital cost curves and equations, EPA compared the costs predicted by the cooling tower capital cost equations to actual costs for cooling tower construction projects provided by cooling tower vendors. EPA obtained data for 20 cooling tower construction projects: nine Douglas fir towers, eight fiberglass towers, one redwood tower, and two towers for which the construction material was unknown (for purposes of comparison, EPA compared these last two towers to predicted costs for redwood towers). In some cases, the project costs did not include certain components such as pumps or basins. Where this was the case, EPA adjusted the project costs as follows:

- where project costs did not include pumps, EPA added $10/gpm to the project costs to account for pumps.
- where project costs did not include pumps and basins, EPA doubled the project costs to account for pumps and basins.

Chart 2-7 at the end of this chapter compares actual capital costs for wet cooling tower projects against predicted costs from EPA's cooling tower capital cost curves, with 25 percent error bars around the cost curve predicted values. This chart shows that, in almost all cases, EPA's cost curves provide conservative cost estimates (erring on the high side) and are within 25 percent or less of actual project costs. In those few cases where the cost curve predictions are not within 25 percent of the actual costs, the difference can generally be attributed to the fact that the constructed cooling towers were designed for temperature deltas different than the 10 °F used for EPA's cost curves.

Operation and Maintenance (O&M) Cost of Cooling Towers

EPA has included the following variables in estimating O&M costs for cooling towers:

C Size of the cooling tower,
C Material from which the cooling tower is built,
C Various features that the cooling tower may include,
C Source of make-up water,
C How blowdown water is disposed, and
C Increase in maintenance costs as the tower useful life diminishes.

For example, if make-up water is obtained from a lesser quality source, additional treatment may be required to prevent biofouling in the tower.

The estimated annual O&M costs presented below are for cooling towers designed at a delta of 10 degrees. To calculate annual O&M costs for various types of cooling towers, EPA made the following assumptions:

- For small cooling towers, the annual O&M costs for chemical costs and routine preventive maintenance is estimated at 5 percent of capital costs. To account for economy of scale in these components of the O&M cost, that percentage is gradually decreased to 2 percent for the largest size cooling tower. EPA notes that, while there appear to be economies of scale for these components of O&M costs, chemical and routine preventive maintenance costs represent a small percentage of the total O&M costs and EPA does not believe there to be significant economies of scale in the total O&M costs.

- 2 percent of the tower flow is lost to evaporation and/or blowdown.

- To account for the costs of makeup water and disposal of blowdown water, EPA used three scenarios at proposal, as documented in the *Economic and Engineering Analyses of the Proposed §316(b) New Facility Rule* (EEA). The first scenario is based on the facility using surface water sources for makeup water and disposing of blowdown water either to a pond or back to the surface water source at a combined cost of $0.5/1000 gallons. The second scenario is based on the facility using gray water (treated municipal wastewater) for makeup water and disposing of the blow down water into a POTW sewer line at a combined cost of $3/1000 gallons. The third scenario is based on the facility using municipal sources for clean makeup water and disposing of the blowdown water into a POTW sewer line at a combined cost of $4/1000 gallons. For the final §316(b) New Facility Rule, EPA based all cooling tower O&M costs on Scenario 1 (use of surface water sources for makeup water and disposal of blowdown water either to a pond or back to the surface water source).

- Based on discussions with industry representatives, the largest component of total O&M costs is the requirement for major maintenance of the tower that occurs after years of tower service, such as around the 10th year and 20th years of service. These major overhauls include repairs to mechanical equipment and replacement of 100 percent of fill material and eliminators.

To account for the variation in maintenance costs among cooling tower types, a scaling factor is used. Douglas Fir is the type with the greatest maintenance cost, followed by Redwood, steel, concrete, and fiberglass. For additional cooling tower features, a scaling factor was used to account for the variations in maintenance (e.g., splash fill and non-fouling film fill are the features with the lowest maintenance costs).

Using the operation cost comparison information published by Mirsky et al. (1992) and maintenance cost assumptions set out above, EPA calculated estimated costs of O&M for various types of cooling towers with and without additional features. EPA then developed cost equations from the generated cost data points, as documented in the proposal EEA. In preparing O&M cost estimates for the final rule, EPA discovered an error in how the costs for major maintenance were calculated in the proposal EEA. In the proposal EEA, these costs were calculated as annual costs following the years that they were to occur. However, some of these costs actually represent one-time costs. This calculation error caused the O&M cost estimates in the proposal EEA to be in error on the high side. EPA's total O&M cost estimates in the proposal EEA were (for Douglas fir cooling towers, for example) about 25-30 percent of the cooling tower capital cost. EPA's revised calculations indicate that the correct value for total O&M costs should be about 50 percent lower. EPA updated the O&M cost curves for the first scenario for the redwood towers which were used in developing cost estimates for the final rule, and for the concrete towers which were used in the sensitivity analysis for the final rule cost estimates. The updated equations and costs are shown in Tables 2-17 through 2-20 for the first scenario for redwood towers with various features. Updated cost curves and equations for O&M costs for redwood and concrete cooling towers are also presented at the end of the chapter. O&M cost curves and equations contained in the EEA for other types of towers and for the other scenarios would need to be updated in a similar manner before being used to develop cost estimates.

Note that these cost estimates and equations are for total O&M costs. Stone and Webster (1992) presents a value for additional annual O&M costs equal to approximately 0.7 percent of the capital costs for a retrofit project. Stone and Webster's estimate is for the amount O&M costs are expected to *increase* when plants with once-through cooling systems are retrofit with cooling towers to become recirculating systems, and therefore do not represent total O&M costs.

Table 2-17. Total Annual O&M Cost Equations for Redwood Towers - 1st Scenario

Cooling Tower Material Type	Total Annual O&M Cost Equations[1]	Correlation Coefficient
Redwood	$y = -4E\text{-}06x^2 + 10.617x + 2055.2$	$R^2 = 0.9999$

1) x is flow in gpm and y is annual O&M cost in dollars.

Table 2-18. Total Estimated Annual O&M Costs for Redwood Towers - 1st Scenario (1999 Dollars)

Flow (gpm)	Redwood Tower
2000	$22,000
4000	$43,000
7000	$76,000
9000	$97,000
11,000	$119,000
13,000	$140,000
15,000	$162,000
17,000	$184,000
18,000	$194,000
22,000	$234,000
25,000	$265,000
28,000	$297,000
29,000	$308,000
31,000	$329,000
34,000	$361,000
36,000	$382,000
45,000	$469,000
47,000	$490,000
56,000	$584,000
63,000	$657,000
67,000	$699,000
73,000	$761,000
79,000	$809,000
94,000	$963,000
102,000	$1,045,000
112,000	$1,147,000
146,000	$1,496,000
157,000	$1,580,000
204,000	$2,015,000

Table 2-19. Total Annual O&M Cost Equations - 1st scenario for Redwood Towers with Environmental Mitigation Features[1]

Type of Tower	O&M Cost Equations[2]	Correlation Coefficient
Non-Fouling Film Fill tower	$y = -4E\text{-}06x^2 + 11.163x + 2053.7$	$R^2 = 0.9999$
Noise reduction (10dBA)	$y = -5E\text{-}06x^2 + 12.235x + 2512.5$	$R^2 = 0.9999$
Hybrid tower (Plume Abatement 32DBT)	$y = -1E\text{-}05x^2 + 21.36x + 5801.6$	$R^2 = 0.9998$
Splash Fill tower	$y = -4E\text{-}06x^2 + 11.163x + 2053.7$	$R^2 = 0.9999$
Dry/wet tower	$y = -1E\text{-}05x^2 + 25.385x + 7328.1$	$R^2 = 0.9998$

1) Features include non-fouling film, noise reduction, plume abatement, or splash fill
2) x is flow in gpm and y is annual O&M cost in dollars.

Table 2-20. Total Estimated Annual O&M Costs - 1st scenario for Redwood with Environmental Mitigation Features (1999 Dollars)

Flows (gpm)	Splash Fill Tower	Non-Fouling Film Fill Tower	Hybrid Tower (Plume abatement (32DBT	Dry/Wet Tower	Noise Reduction (10dBA)
2000	$24,000	$23,000	$44,000	$25,000	$52,000
4000	$47,000	$45,000	$88,000	$50,000	$104,000
7000	$83,000	$79,000	$153,000	$87,000	$182,000
9000	$106,000	$102,000	$197,000	$112,000	$234,000
11,000	$130,000	$125,000	$241,000	$137,000	$286,000
13,000	$153,000	$148,000	$284,000	$162,000	$339,000
15,000	$177,000	$170,000	$328,000	$187,000	$391,000
17,000	$201,000	$193,000	$372,000	$212,000	$443,000
18,000	$212,000	$204,000	$394,000	$224,000	$469,000
22,000	$256,000	$245,000	$469,000	$269,000	$558,000
25,000	$290,000	$279,000	$533,000	$306,000	$634,000
28,000	$325,000	$312,000	$597,000	$342,000	$710,000
29,000	$337,000	$323,000	$619,000	$354,000	$735,000
31,000	$360,000	$346,000	$661,000	$379,000	$786,000
34,000	$395,000	$379,000	$725,000	$416,000	$862,000
36,000	$418,000	$402,000	$768,000	$440,000	$913,000
45,000	$514,000	$493,000	$935,000	$539,000	$1,110,000
47,000	$537,000	$515,000	$977,000	$563,000	$1,159,000
56,000	$640,000	$613,000	$1,164,000	$671,000	$1,381,000
63,000	$720,000	$690,000	$1,309,000	$755,000	$1,554,000
67,000	$766,000	$733,000	$1,392,000	$803,000	$1,652,000
73,000	$834,000	$799,000	$1,517,000	$875,000	$1,800,000
79,000	$888,000	$849,000	$1,598,000	$928,000	$1,893,000
94,000	$1,057,000	$1,010,000	$1,901,000	$1,104,000	$2,253,000
102,000	$1,147,000	$1,096,000	$2,063,000	$1,198,000	$2,445,000
112,000	$1,259,000	$1,203,000	$2,265,000	$1,315,000	$2,684,000
146,000	$1,642,000	$1,569,000	$2,953,000	$1,714,000	$3,499,000
157,000	$1,737,000	$1,655,000	$3,088,000	$1,806,000	$3,654,000
204,000	$2,219,000	$2,109,000	$3,900,000	$2,298,000	$4,607,000

Variable speed pumps

For a power plant operating at near constant power output (e.g., at or near capacity), the amount of heat rejected through the cooling system will also remain nearly constant regardless of changes in ambient conditions. In cooling systems where heat from steam condensation is transferred to cooling water (i.e., those that use surface condensers), the amount of heat rejected can be measured as the product of the cooling water flow rate times the difference in temperature of the cooling water between the condenser inlet and outlet. If the cooling water flow rate remains constant, then the temperature difference will also remain relatively constant regardless of changes in the inlet temperature. Therefore, a decrease in the cooling water temperature at the condenser inlet will result in a similar decrease in the condenser outlet temperature and a corresponding decrease in the temperature of the condenser surface where steam is condensed.

As described in Chapter 3 on the energy penalty, a decrease in condenser temperatures will produce a decrease in the turbine exhaust, which can result in an increase in the turbine efficiency. Thus, seasonal changes in ambient source water temperature will result in changes in the condenser temperatures, which can affect the steam turbine efficiency. However, as the ambient and condenser temperatures progressively drop, the system performance can approach a point where turbine efficiency no longer increases and may begin to decrease. In addition, significantly reduced turbine exhaust pressures can result in condensed moisture within the turbine, which can damage turbine blades and further reduce turbine efficiency. Thus, progressive reductions in the cooling water temperature in a cooling system operating at a constant cooling water flow rate may approach a point where continued reduction in ambient temperatures results in detrimental or less than optimal operating conditions. The ambient conditions at which this begins to occur will be dependent on the cooling and turbine system design, which is often subject to site-specific and economic considerations.

In a once-through cooling system, one method of controlling the steam condenser temperature is to control the cooling water flow rate. If the heat rejection rate remains relatively constant (near constant plant output), a reduction in the cooling water flow rate will result in an increase in the difference in temperature of the cooling water between the condenser inlet and outlet (referred to as the "range"). An increase in the range will result in an increase in the temperature of the steam condensing surface. Therefore, through careful control of the cooling water flow rate, the condenser temperature can be controlled such that the power plant turbine performance does not degrade and damaging conditions are avoided. Thus, the ability to reduce cooling water flow rate can provide for improved plant operation as well as reducing the environmental impacts of cooling water withdrawals from surface waters.

Use of variable speed pumps is an efficient method for attaining control of the cooling water flow rate and thus the condenser performance. Variable frequency drives are used to vary the pump speed, which in turn allows the flow rate to be adjusted through a range from zero to its maximum output.

There are some limitations on the range of flow rates that can be used. Most once-through cooling systems discharge to surface waters under an NPDES permit, which often includes discharge limits on both the maximum temperature (a concern during the warmer months) and the temperature increase of the discharge over the intake temperature (a concern if flow rates are adjusted). Exceedence of the maximum temperature limit can be avoided by operating at the maximum cooling water flow rate and, when necessary, reducing the plant output (i.e., the heat rejection rate). The limit on temperature increase may create an effective lower limit on the cooling water flow rate (at a given heat rejection rate) in the sense that further reduction in cooling water flow rate would result in a temperature rise that exceeded the NPDES temperature increase limitation. These constraints, however, do not prevent varying the cooling water flow rate; rather, they set the range in flow rates (for a given plant power output level) over which the system may operate. Note that varying the cooling water flow rate does not change the amount of heat being discharged. Rather, it only affects the "concentration" of the heat. Limitation of the temperature increase is intended to reduce detrimental impacts on entrained organisms, as well as on those in the mixing zone downstream.

EPA chose to include the cost of variable frequency drives as part of the pump costs for the post-compliance cost estimates for all once-though systems and for wet tower system intakes. While condenser performance is not affected by using variable speed pumps in the wet tower make-up water intake, EPA included them to provide greater process control. For the baseline system costs to which post-compliance costs are compared, EPA used the costs for constant speed pumps even though facilities may install variable speed pumps regardless of the rule's implementation. EPA chose this approach as a means for generating a conservative (on the high side) compliance cost estimate.

A recent evaluation of the equipment cost for variable speed pumps indicates that EPA may have underestimated the cost for the variable frequency drive component of the pumping system. Recent investigation of estimated costs for VFDs from other sources indicates that the unit cost of $100/Hp obtained from the original contact is lower than estimates from these other sources. EPA has re-evaluated the costs for addition of VFDs using data from these other sources. See DCN 3-3038. EPA finds that the contribution to capital cost from the uncertainty of variable speed drive costs is not appreciable for the final annualized compliance costs of the effected facilities. Analogous to the sensitivity analysis performed on the material of construction of the cooling towers of coal-fired plants (i.e., concrete vs. redwood), the percentage of capital cost due to the uncertainty, when amortized over the appropriate period would not significantly influence total annualized compliance costs.

Pump Equipment Cost Development

The distinction between constant and variable speed pumping systems is the presence of variable frequency drives (VFD). A pump supplier estimated that the unit cost of the variable frequency drives was approximately $100/Hp (Flory 2001). This unit cost is consistent with the cost of a VFD of $20,000 to $30,000 cited for a 200 Hp fan for an air cooled condenser (Tallon 2001). Table 2-21 provides a summary of the data that EPA used to develop the equipment costs for constant speed and variable speed pumps.

Table 2-21: Pump Cost Data (Source: Flory 2001)

Flow (gpm)	Brake-Hp at 50 ft Pumping Head[1]	Pump and Motor with Freight and Tax[2]	Variable Frequency Drive	Total with Variable Frequency Drive
5,000	90	$23,000	$9,015	$32,015
50,000	902	$115,000	$90,150	$205,150
250,000	3,606	$402,500	$360,600	$763,100

[1] Based on flow and a pumping head of 50 ft.
[2] Includes 15 percent for cost of freight and tax.

EPA also included pump installation costs, with the value scaled from 60 percent of equipment costs at 500 gpm to 40 percent at 350,000 gpm.

Table 2-22 presents cost equations for estimating capital costs for variable speed pumps. Cost curves and equations for variable speed pumps are also presented at the end of this chapter.

Table 2-22. Capital Cost Equations for Constant Speed and Variable Speed Pumps

Pump Type	Capital Cost Equation[1]	Correlation Coefficient
Constant Speed	$y = 1.6859x + 13369$	$R^2 = 0.9998$
Variable Speed	$y = 3.1667x + 16667$	$R^2 = 1$

1) x is flow in gpm and y is cost in dollars.

Using non-surface water sources

A facility may be able to obtain some of its cooling water from a source other than the surface water it is using (WWTP gray water, ground water, or municipal water supply) and thereby reduce the volume of its withdrawals from the surface water and meet the percent of flow requirements. Some facilities may only need to use this alternate source during low flow periods in the surface water source. To use this option, a facility would need to build a pond or basin for the supplemental cooling water.

A facility using gray water may need to install some water treatment equipment (e.g., sedimentation, filtration) to ensure that its discharge of the combined source water and gray water meets any applicable effluent limits. For costing purposes, EPA has assumed that a facility would only need to install treatment for gray water in situations where treatment would have been required for river intake water. Therefore, no additional (i.e., "new") costs are incurred for treatment of gray water after intake or before discharge.

See the end of this chapter for cost curves and equations for estimating gray water and municipal water costs.

2.9.2 Reducing Design Intake Velocity

Passive screens

Passive screens, typically made of wedge wire, are screens that use little or no mechanical activity to prevent debris and aquatic organisms from entering a cooling water intake. The screens reduce impingement and entrainment by using a small mesh size for the wedge wire and a low through-slot velocity that is quickly dissipated. The main components of a passive screening system are typically the screen(s), framing, an air backwash system if needed, and possibly guide rails depending on the installation location.

Passive screens vary in shape and form and include flat panels, curved panels, tee screens, vee screens, and cylinder screens. Screen dimensions (width and depth) vary; they are generally made to order with sizing as required by site conditions. Panels can be of any size, while cylinders are generally in the 12" to 96" diameter range. The main advantages of passive intake systems are:

- They are fish-friendly due to low slot velocities (peak <0.5 fps), and
- They have no moving parts and thus minimal O&M costs.

New passive intake screens have higher capacity (due to higher screen efficiency) than older versions of passive screens. Wedge wire screens are effective in reducing impingement and entrainment as long as a sufficiently small screen slot size is used and ambient currents have enough velocity to move aquatic organisms around the screen and flush debris away.

The key parameters and additional features that are considered in estimating the cost of passive/wedge wire screening systems on CWIS are:

- Size of screen and flow rate (i.e., volume of water used),
- Size of screen slots/openings,
- Screen material,
- Water depth,
- Water quality (debris, biological growth, salinity), and
- Air backwash systems.

The size and material of a screen most affect cost. Branched intakes, with a screen on each branch, can be used for large flows. Screen slot size also impacts the size of a screen. A smaller slot opening will result in a larger screen being required to keep the peak slot velocity under 0.5 fps.

Site-specific conditions significantly affect costs of the screen(s). The water depth affects equipment and installation costs because structural reinforcement is required as depth increases, air backwash system capacities need to be increased due to the reduced air volume at greater depths, and installation is generally more difficult. The potential for clogging from debris and fouling from biogrowth are water quality concerns that affect costs. The amount and type of debris influence the size of openings in the screen, which affects water flow through the screen and thus screen size. Finer debris may require a smaller slot opening to prevent debris from entering and clogging the openings.

Generally, speed and flow of water do not affect the installation cost or the operation of passive intakes, however there must be adequate current in the source water to carry away debris that is backwashed from the screen so that it does not become (re)clogged. It is recommended as good engineering practice that the axis of the screen cylinder be oriented parallel with the water flow to minimize fish entrainment and to aid in removal of debris during air backwash. The effects of the presence of sensitive species or certain types of species affect the design of the screen and may increase screen cost. For example, the lesser strength of a local species could result in the need for a peak velocity less than 0.5 fps which would result in a larger screen. Biofouling from the attachment of zebra mussels and barnacles and the growth of algae may necessitate the use of a special screen material, periodic flushing with biocides, and in limited cases, manual cleaning by divers. For example, the presence of zebra mussels often requires the use of a special alloy material to prevent attachment to the screen assembly.

The level of debris in the water also affects whether an air backwash system is needed and how often it is used. Heavy debris loadings may dictate the need for more frequent air backwashing. If the air backwash frequency is high enough, a larger compressor may be required to recharge the accumulator tank more quickly.

Another water quality factor that affects screen cost is water corrosiveness (e.g., whether the intake water is seawater, freshwater, or brackish). Most passive screens are manufactured in either 304 or 316 stainless steel for freshwater installations. The 316L stainless steel can be used for some saltwater installations, but has limited life. Screens made of copper-nickel alloys (70/30 or 90/10) have shown excellent corrosion resistance in saltwater, however they are significantly more expensive than stainless steel (50 percent to 100 percent greater in cost, i.e., can be double the cost).

Capital Costs

EPA assumed that the capital cost of passive screens will be 60 percent of the capital cost of a basic traveling screen of similar size. This assumption is based on discussions with industry representatives. The lower capital cost is because passive screen systems have lower onshore site preparation and installation costs (no extensive mechanical equipment as in the traveling screens) and are easier to install in offshore situations. The estimated capital costs for passive screens are shown in Table 2-23, corresponding to the flows shown in Table 2-31 for a through screen velocity of 0.5 fps. Passive screens for sizes larger than those shown in Table 2-23 will generate flows higher than 50,000 gpm. For flows greater than 50,000 gpm, particularly when water is drawn in from a river, the size of the CWIS site becomes very big and the necessary network fanning for intake points and screens generally makes passive screen systems unfeasible.

Table 2-23 Estimated Capital Costs for a Through Flow Passive Water Screen Stainless Steel 304 - Standard Design[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$34,200	$56,100	$91,800	$128,700
25	$49,800	$84,900	$140,400	(2)
50	$74,400	$122,700	(2)	(2)
75	$99,000	(2)	(2)	(2)
100	$135,600	(2)	(2)	(2)

1) Cost estimate includes stainless steel 304 structure.
2) Not estimated because passive screen systems of this size are not feasible.

As noted above, the capital costs for special screen materials (e.g., copper-nickel alloys) are typically 50 percent to 100 percent higher.

Table 2-24 presents cost equations for estimating capital costs for passive screens. The "x" in the equation represents the flow volume in gpm and the "y" value is the passive screen total capital cost. Cost equations associated with a flow of 1 fps are provided for comparative purposes.

Table 2-24. Capital Cost Equations for Passive Screens

Screen Width (ft)	Passive Screens Velocity 0.5 ft/sec		Passive Screens Velocity 1ft/sec	
	Equation[1]	Correlation Coefficient	Equation[1]	Correlation Coefficient
2	$y = 3E\text{-}08x^3 - 0.0008x^2 + 12.535x + 11263$	$R^2 = 0.9991$	$y = 5E\text{-}09x^3 - 0.0002x^2 + 6.5501x + 9792.6$	$R^2 = 0.9991$
5	$y = 0.0002x^2 + 1.5923x + 47041$	$R^2 = 1$	$y = 4E\text{-}05x^2 + 1.0565x + 43564$	$R^2 = 1$
10	$y = 3.7385x + 58154$	$R^2 = 1$	$y = 1.8x + 59400$	$R^2 = 1$

1) x is the flow in gpm y is the capital cost in dollars.

See the end of this chapter for cost curves and equations.

Operation and Maintenance (O&M) Costs for Passive Screens

Generally, there are no appreciable O&M costs for passive screens unless there are biofouling problems or zebra mussels in the environment. Biofouling problems can be remedied through the proper choice of materials and periodic mechanical cleaning. Screens equipped with air backwash systems require periodic compressor/motor/valve maintenance. Therefore, EPA has estimated zero O&M costs for passive screens.

Velocity Caps

The cost driver of velocity caps is the installation cost. Installation is carried out underwater where the water intake mouth is modified to fit the velocity cap over the intake. EPA estimated capital costs for velocity caps based on the following assumptions:

- Four velocity caps can be installed in a day,
- Cost of the installation crew is similar to the cost of the water screen installation crew (see Box 2-1),
- To account for the difficulty in installing in deep water, an additional work day is assumed for every increase in depth size category, and
- Equipment cost for a velocity cap is assumed to be 25 percent of the velocity cap installation cost. In our BPJ, this is a conservatively high estimate of the cost of velocity cap material and delivery to the installation site.

Based on these assumptions, EPA calculated estimated costs for velocity caps, which are shown in Tables 2-25 and 2-26. EPA calculated the number of velocity caps needed for various flow sizes based on a flow velocity of 0.5ft/sec and assuming that the intake area to be covered by the velocity cap is 20 ft^2 which is the area comparable to a pipe diameter of about 5 feet. For flows requiring pipes larger than this, EPA assumed, for velocity cap costing purposes, that multiple intake pipes with a standard, easy-to-handle pipe diameter will be used rather than larger-diameter, custom made pipes (based on BPJ). Cost curves and equations are at the end of the chapter.

Table 2-25. Estimated Velocity Cap Installation Costs (1999 Dollars)

Flow (gpm) (No. of velocity caps)	Water Depth (ft)				
	8	20	30	50	65
Up to 18,000 (4 VC)	$8000	$12,500	$17,000	$21,500	$26,000
18,000 ≤ flow <35,000 (9 VC)	$12,500	$17,000	$21,500	$26,000	$30,500
35,000≤ flow <70,000 (15 VC)	$21,500	$26,000	$30,500	$35,000	$39,500
70,000≤ flow <100,000 (23 VC)	$30,500	$35,000	$39,500	$44,000	$48,500
157,000 (35 VC)	$44,000	$48,500	$53,000	$57,500	$62,000
204,000 (46 VC)	$57,500	$62,000	$66,500	$71,000	$75,500

Table 2-26. Estimated Velocity Cap Equipment and Installation Costs (1999 Dollars)

Flow (gpm) (No. of velocity caps)	Water Depth (ft) 8	20	30	50	65
Up to 18,000 (4 VC)	$10,000	$15,625	$21,250	$26,875	$32,500
18,000 ≤ flow <35,000 (9 VC)	$15,625	$21,250	$26,875	$32,500	$38,125
35,000≤ flow <70,000 (15 VC)	$26,875	$32,500	$38,125	$43,750	$49,375
70,000≤ flow <100,000 (23 VC)	$38,125	$43,750	$49,375	$55,000	$60,625
157,000 (35 VC)	$55,000	$60,625	$66,250	$71,875	$77,500
204,000 (46 VC)	$71,875	$77,500	$83,125	$88,750	$94,375

Table 2-27. Cost Equations for Velocity Cap Capital Costs

Flow (gpm) (No. of velocity caps)	Velocity Cap Capital Cost Equation	Correlation Coefficient
Up to 18,000 (4 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 4212.7$	$R^2 = 0.9962$
18,000 ≤ flow <35,000 (8 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 9837.7$	$R^2 = 0.9962$
35,000≤ flow <70,000 (16 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 21088$	$R^2 = 0.9962$
70,000≤ flow <100,000 (24 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 32338$	$R^2 = 0.9962$
157,000 (35 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 49213$	$R^2 = 0.9962$
204,000 (46 VC)	$y = 0.071x^3 - 9.865x^2 + 775.03x + 66088$	$R^2 = 0.9962$
1) x represents the water depth in feet and y is the capital cost in dollars.		

Installation of Gunderboom Marine Life Exclusion Systems (MLES)

A Gunderboom Marine Life Exclusion System (MLES) utilizes a stationary double-layered filter barrier curtain to prevent entrainment and impingement of aquatic organisms around the CWIS. The MLES consists of a patented filter curtain made of polypropylene/polyester fabric suspended through the full depth of the water column.

Gunderbooms allow for the passage of water, while preventing the passage of aquatic life and particulates into the CWIS. This is achieved by surrounding the intake structure with the filter curtain and sealing the curtain against the seafloor and shoreline structures. Water passing through the curtain does so at a lower velocity than that of the surrounding stream or water body. The MLES system is designed to allow a through-fabric velocity of approximately 0.01 to 0.05 feet/second (fps), yielding an average velocity of approximately 0.02 fps. The system may be designed for lower or higher flows, as needed.

The Gunderboom is enhanced by an automated "Air Burst" cleaning system. This system uses periodic bursts of air between the two fabric layers to free any organisms or debris caught against the filter curtain.

Based on information provided by the manufacturer, the main advantages of the MLES system are:

- The system has been demonstrated to reduce entrainment by at least 80 percent. According to Gunderboom, the MLES can produce up to 100 percent exclusion for many applications.
- The Gunderboom fabric consists of a minute fiber matting with an Apparent Opening Size (AOS) of approximately 20 microns. As such, the system has been shown to significantly reduce turbidity, suspended solids, coliform bacteria, and other particulate-associated contaminants. For MLES systems, perforations ranging in diameter from 0.4 mm to 3.0 mm or more are added to increase the flow of water through the fabric. Perforation size can be customized to prevent entrainment of the specific eggs or fish larvae that are present at the installation site.
- The double fabric layer system with an "Air Burst" Technology cleaning system reduces overall O&M costs. Since debris and sediment are excluded, the Gunderboom may also help reduce O&M costs for intake screens, condensers and other parts of the cooling water system.
- Once the anchoring and "Air Burst" Technology have been installed, deployment of the MLES can be achieved in two to three weeks, barring logistics or weather problems, and requires no or minimal plant shutdown.

Gunderbooms are designed and engineered for the specific site at which they are to be installed. The designs may include plant intakes, floating walkways, pile-supported structures, concrete submerged structures, removable panels and solid frames. However, and in general, the key parameters that may have a significant impact on estimating the cost of the Gunderboom system are:

- CWIS flow rates,
- Physical factors of the water body and facility intake structure,
- Target species and life stages,
- Water body characteristics, including elevation changes, currents, wind-induced wave action and suspended sediment concentrations,
- Degree of automation, and
- Water quality

Factors such as the CWIS flow rates and physical factors of the water body and intake structure affect the capital cost because they determine the required size of the Gunderboom filter curtain. Other factors such as water quality and degree of automation contribute to greater O&M costs.

Installation

The Gunderboom MLES installation cost is largely a function of site conditions. Strong current flow, winds, wave action, and low accessibility can make installation more difficult. However, for the purpose of developing national cost estimates, EPA did not consider abnormal conditions in developing its cost equations and cost curves.

Capital Costs

EPA estimated capital costs of the MLES system based on information submitted by representatives of Gunderboom, Inc. Low and high capital cost estimates were provided for flows of 10,000, 104,000, and 347,000 gpm. EPA then calculated average capital costs as shown in Table 2-28. For purposes of estimating costs, EPA assumed that a simple floating configuration, as opposed to a rigid configuration, would be used.

Table 2-28. Estimated Capital Costs for a Simple Floating Gunderboom Structure

Flow (gpm)	Low Cost	High Cost	Average Cost
10,000	$500,000	$700,000	$600,000
104,000	$1,800,000	$2,500,000	$2,150,000
347,000	$5,700,000	$7,800,000	$6,750,000

According to the manufacturers, the cost of a fixed system for a CWIS of 10,000 gpm capacity ranges between $0.7M and $1.5M while the cost of a complete independent system can be greater than $2M.

Operation and Maintenance (O&M) Costs

EPA also estimated O&M costs of the MLES system based on information submitted by representatives of Gunderboom, Inc. Low and high O&M cost estimates were provided for flows of 10,000, 104,000, and 347,000 gpm. EPA then calculated average O&M costs as shown in Table 2-29. Again, a simple floating configuration was assumed.

Table 2-29. Estimated O&M Costs for a Simple Floating Gunderboom Structure

Flow (gpm)	Low Cost	High Cost	Average Cost
10,000	$100,000	$300,000	$200,000
104,000	$150,000	$300,000	$225,000
347,000	$500,000	$700,000	$600,000

EPA plotted the high, low and average capital as well as the average O&M costs, then fitted equations and curves to the data as shown in Chart 2-30. In the cost equations, "x" represents the flow volume in gpm, and "y" represents the total capital or annual O&M cost.

Branching the intake pipe to increase the number of openings or widening the intake pipe

Branching an intake pipe involves the use of fittings to attach the separate pipe sections. See the end of this chapter for costs curves and equations.

2.9.3 Design and Construction Technologies to Reduce Damage from I&E

Installation of traveling screens with fish baskets

Single-entry, single-exit vertical traveling screens (conventional traveling screens) contain a series of wire mesh screen panels that are mounted end to end on a band to form a vertical loop. As water flows through the panels, debris and fish that are larger than the screen openings are caught on the screen or at the base of each panel in a basket. As the screen rotates around, each panel in turn reaches a top area where a high-pressure jet spray wash pushes debris and fish from the basket into a trash trough for disposal. As the screen rotates over time, the clean panels move down, back into the water to screen the intake flow.

Conventional traveling screens can be operated continuously or intermittently. However, when these screens are fitted with fish baskets (also called modified conventional traveling screens or Ristroph screens), the screens must be operated continuously so that fish that are collected in the fish baskets can be released to a bypass/return using a low pressure spray wash when the basket reaches the top of the screen. Once the fish have been removed, a high pressure jet spray wash is typically used to remove debris from the screen. In recent years, the design of fish baskets has been refined (e.g., deeper baskets, smoother mesh, better balance) to decrease chances of injury and mortality and to better retain fish (i.e., prevent them from flopping out and potentially being injured). Methods used to protect fish include the Stabilized Integral Marine Protective Lifting Environment (S.I.M.P.L.E.) developed by Brackett Green and the Modified Ristroph design by U.S. Filter.

U.S. Filter's conventional (through flow) traveling screens are typically manufactured in widths ranging from two feet to at least 14 feet, for channel depths of up to 100 feet, although custom design is possible to fit other dimensions.

Flow

To calculate the flow through a screen panel, the width of the screen panel is multiplied by the water depth and, using the desired flow velocities (1 foot per second and 0.5 foot per second), is converted to gallons per minute assuming a screen efficiency of 50 percent. The calculated flows for selected screen widths, water depths, and well depths are presented in Tables 2-30 and 2-31. For flows greater than this, a facility would generally install multiple screens or use a custom design.

Well depth includes the height of the structure above the water line. The well depth can be more than the water depth by a few to tens of feet. The flow velocities used are representative of a flow speed that is generally considered to be fish friendly particularly for sensitive species (0.5 fps), and a flow speed that may be more practical for some facilities to achieve but typically provides less fish protection. The water depths and well depths are approximate and may vary based on actual site conditions.

Table 2-30. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 1.0 fps

Well Depth (ft)	Water Depth (ft)	Basket Panel Screening Width (ft)			
		2	5	10	14
10	8	4000	9000	18,000	25,000
25	20	9000	22,000	45,000	63,000
50	30	13,000	34,000	67,000	94,000
75	50	22,000	56,000	112,000	157,000
100	65	29,000	73,000	146,000	204,000

Table 2-31. Average Flow Through A Traveling Water Screen (gpm) for a Flow Velocity of 0.5 fps

Well Depth (ft)	Water Depth (ft)	Basket Screening Panel Width (ft)			
		2	5	10	14
10	8	2000	4000	9000	13,000
25	20	4000	11,000	22,000	31,000
50	30	7000	17,000	34,000	47,000
75	50	11,000	28,000	56,000	79,000
100	65	15,000	36,000	73,000	102,000

Capital Costs

Equipment Cost

Basic costs for screens with flows comparable to those shown in the above tables are presented in Tables 2-32 and 2-33. Table 2-32 contains estimated costs for basic traveling screens without fish handling features, that have a carbon steel structure coated with epoxy paint. The costs presented in Table 2-33 are for traveling screens with fish handling features including a spray system, a fish trough, housings and transitions, continuous operating features, a drive unit, frame seals, and engineering. Installation costs and spray pump costs are presented separately below.

Table 2-32. Estimated Equipment Cost for Traveling Water Screens Without Fish Handling Features[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$30,000	$35,000	$45,000	$65,000
25	$35,000	$45,000	$60,000	$105,000
50	$55,000	$70,000	$105,000	$145,000
75	$75,000	$100,000	$130,000	$175,000
100	$115,000	$130,000	$155,000	$200,000

1) Cost includes carbon steel structure coated with epoxy paint and non-metallic trash baskets with Type 304 stainless mesh and intermittent operation components.

Source: Vendor estimates.

Table 2-33. Estimated Equipment Cost for Traveling Water Screens With Fish Handling Features[1] (1999 Dollars)

Well depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$63,500	$73,500	$94,000	$135,500
25	$81,250	$97,500	$133,000	$214,000
50	$122,500	$152,000	$218,000	$319,500
75	$163,750	$210,000	$283,000	$414,500
100	$225,000	$267,500	$348,000	$504,500

1) Cost includes carbon steel screen structure coated with epoxy paint and non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, and engineering (averaged over 5 units). Costs do *not* include differential control system, installation, and spray wash pumps.

Source: Vendor estimates.

Installation Cost

Installation costs of traveling screens are based on the following assumptions of a typical average installation requirement for a hypothetical scenario. Site preparation and earth work are calculated based on the following assumptions:

- ***Clearing and grubbing*****:** Clearing light to medium brush up to 4" diameter with a bulldozer.
- ***Earthwork*****:** Excavation of heavy soils. Quantity is based on the assumption that earthwork increases with screen width.
- ***Paving and surfacing*****:** Using concrete 8" thick and assuming that the cost of pavement attributed to screen installation is 6x3 yards for the smallest screen and 25x6 yards for the largest screen.
- ***Structural concrete*****:** The structural concrete work attributed to screen installation is four 12"x12" reinforced concrete columns with depths varying between 1.5 yards and 3 yards. There is more structural concrete work for a water intake structure, however, for new source screens and retrofit screens, only a portion of the intake structural cost can be justifiably attributed to the screen costs. For new screens, most of the concrete structure work is for developing the site to make it accessible for equipment and protect it from hydraulic elements, which are necessary for constructing the intake itself. For retrofits, some of the structural concrete will already exist and some of it will not be needed since the intake is already in place and only the screen needs to be installed. All unit costs used in calculating on-shore site preparation were obtained from *Heavy Construction Cost Data 1998* (R. S. Means, 1997b).

Table 2-34 presents site preparation installation costs that apply to traveling screens both with and without fish handling features. The total onshore construction costs are for a screen to be installed in a 10-foot well depth. Screens to be installed in deeper water are assumed to require additional site preparation work. Hence for costing purposes it is assumed that site preparation costs increase at a rate of an additional 25 percent per depth factor (calculated as the ratio of the well depth to the base well depth of 10 feet) for well depths greater than 10 feet. Table 2-35 presents the estimated costs of site preparation for four sizes of screen widths and various well depths.

Table 2-34. Estimated Installation (Site Preparation) Costs for Traveling Water Screens Installed at a 10-foot Well Depth (1999 Dollars)

Screen Width (ft)	Clearing and Grabbing (acre)	Clearing Cost[1]	Earth Work (cy)	Earth Work Cost[1]	Paving and Surfacing Using Concrete (sy)	Paving Cost[1]	Structural Concrete (cy)	Structural Cost	Total Onshore Construction Costs
2	0.1	$250	200	$17,400	18	$250	0.54	$680	$19,000
5	0.35	$875	500	$43,500	40	$560	0.63	$790	$46,000
10	0.7	$1,750	1000	$87,000	75	$1,050	0.72	$900	$91,000
14	1	$2,500	1400	$121,800	150	$2,100	1.08	$1,350	$128,000

ft = feet, cy=cubic yard, sy=square yard
1) Clearing cost @ $2,500/acre, earth work cost @ $87/cubic yard, paving cost @ $14/square yard, structural cost @ $1,250/cubic yard.

Source of unit costs: *Heavy Construction Cost Data 1998* (R.S. Means, 1997b).

Table 2-35. Estimated Installation (Site Preparation, Construction, and Onshore Installation) Costs for Traveling Water Screens of Various Well Depths (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft)			
	2	5	10	14
10	$19,000	$46,000	$91,000	$128,000
25	$31,000	$75,000	$148,000	$208,000
50	$43,000	$104,000	$205,000	$288,000
75	$55,000	$132,000	$262,000	$368,000
100	$67,000	$161,000	$319,000	$448,000

Source: R.S. Means (1997b) and vendor estimates.

EPA developed a hypothetical scenario of a typical underwater installation to estimate an average cost for underwater installation costs. EPA estimated costs of personnel and equipment per day, as well as mobilization and demobilization. Personnel and equipment costs would increase proportionately based on the number of days of a project, however mobilization and demobilization costs would be relatively constant regardless of the number of days of a project since the cost of transporting personnel and equipment is largely independent of the length of a project. The hypothetical project scenario and estimated costs are presented in Box 2-1. Hypothetical scenario was used to develop installation cost estimates as function of screen width/well depth. Installation costs were then included with total cost equations. To cost facilities, EPA selected appropriate screen width based on flow.

As shown in the hypothetical scenario in Box 2-1, the estimated cost for a one-day installation project would be $8,000 ($4,500 for personnel and equipment, plus $3,500 for mobilization and demobilization). Using this one-day cost estimate as a basis, EPA generated estimated installation costs for various sizes of screens under different scenarios. These costs are presented in Table 2-35. The baseline costs for underwater installation include the costs of a crew of divers and equipment including mobilization and demobilization, divers, a barge, and a crane. The number of days needed is based on a minimum of one day for a screen of less than 5 feet in width and up to 10 feet in well depth. Using best professional judgement (BPJ), EPA estimated the costs for larger jobs assuming an increase of two days for every increase in well depth size and of one day for every increase in screen width size.

Box 2-1. Example Scenario for Underwater Installation of an Intake Screen System

This project involves the installation of 12, t-24 passive intake screens onto a manifold inlet system. Site conditions include a 20-foot water depth, zero to one-foot underwater visibility, 60-70 ^{N}F water temperature, and fresh water at an inland. The installation is assumed to be 75 yards offshore and requires the use of a barge or vessel with 4-point anchor capability and crane.

Job Description:
Position and connect water intake screens to inlet flange via 16 bolt/nut connectors. Lift, lower, and position intake screens via crane anchored to barge or vessel. Between 4 and 6 screens of the smallest size can be installed per day per dive team, depending on favorable environmental conditions.

Estimated Personnel Costs:
Each dive team consists of 5 people (1 supervisor, 2 surface tenders, and 2 divers), the assumed minimum number of personnel needed to operate safely and efficiently. The labor rates are based on a 12-hour work day. The day rate for the supervisor is $600. The day rate for each diver is $400. The day rate for each surface tender is $200. Total base day rate per dive team is $1,800.

Estimated Equipment Costs:
Use of hydraulic lifts, underwater impact tools, and other support equipment is $450 per day. Shallow water air packs and hoses cost $100 per day. The use of a crane sufficient to lift the 375 lb t-24 intakes is $300 per day. A barge or vessel with 4-point anchor capability can be provided by either a local contractor or the dive company for $1,800 per day (cost generally ranges from $1,500-$2,000 per day). This price includes barge/vessel personnel (captain, crew, etc) but the barge/vessel price does not include any land/waterway transportation needed to move barge/vessel to inland locations. Using land-based crane and dive operations can eliminate the barge/vessel costs. Thus total equipment cost is $2,650 per day.

Estimated Mobilization and Demobilization Expenses:
This includes transportation of all personnel and equipment to the job site via means necessary (air, land, sea), all hotels, meals, and ground transportation. An accurate estimate on travel can vary wildly depending on job location and travel mode. For this hypothetical scenario, costs are estimated for transportation with airfare, and boarding and freight and would be $3,500 for the team (costs generally range between $3,000 and $4,000 for a team).

Other Considerations:
Uncontrollable factors like weather, water temperature, water depth, underwater visibility, currents, and distance to shore can affect the daily production of the dive team. These variables always have to be considered when a job is quoted on a daily rate. Normally, the dive-company takes on the risks for these variables because the job is quoted on a "to completion" status. These types of jobs usually take a week or more for medium to large-size installations.

Total of Estimated Costs:
The final estimated total for this hypothetical job is nearly $4500 per day for personnel and equipment. For a three-day job, this would total about $13,500. Adding to this amount about $3,500 for mobilization and demobilization, the complete job is estimated at $17,000.

Note: Costs for a given project vary greatly depending on screen size, depth of water, and other site-specific conditions such as climate and site accessibility.

Table 2-36. Estimated Underwater Installation Costs for Various Screen Widths and Well Depths[1] (1999 Dollars)				
Well Depth (ft)	**Basket Screening Panel Width (ft)**			
	2	**5**	**10**	**14**
10	$8,000	$12,500	$17,000	$21,500
25	$17,000	$21,500	$26,000	$30,500
50	$26,000	$30,500	$35,000	$39,500
75	$35,000	$39,500	$44,000	$48,500
100	$44,000	$48,500	$53,000	$57,500

1) Based on hypothetical scenario of crew and equipment costs of $4,500 per day and mobilization and demobilization costs of $3,500 (see Box 2-1).

Table 2-37 presents total estimated installation costs for traveling screens. Installation costs for traveling screens with fish handling features and those without fish handling features are assumed to be similar.

Table 2-37. Estimated Total Installation Costs for Traveling Water Screens[1] (1999 Dollars)				
Well Depth (ft)	**Basket Screening Panel Width (ft)**			
	2	**5**	**10**	**14**
10	$27,000	$58,500	$108,000	$149,500
25	$48,000	$96,500	$174,000	$238,500
50	$69,000	$134,500	$240,000	$327,500
75	$90,000	$171,500	$306,000	$416,500
100	$111,000	$209,500	$372,000	$505,500

1) Includes site preparation, and onshore and underwater construction and installation costs.

Total Estimated Capital Costs

The installation costs in Table 2-37 were added to the equipment costs in Tables 2-32 and 2-33 to derive total equipment and installation costs for traveling screens with and without fish handling features. These estimated costs are presented in Tables 2-38 and 2-39. The flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables 2-30 and 2-31 for flow velocities of 1.0 fps and 0.5 fps, respectively.

Table 2-38. Estimated Total Capital Costs for Traveling Screens Without Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)

Well Depth (ft)	Screening Basket Panel Width (ft) 2	5	10	14
10	$57,000	$93,500	$153,000	$214,500
25	$83,000	$141,500	$234,000	$343,500
50	$124,000	$204,500	$345,000	$472,500
75	$165,000	$271,500	$436,000	$591,500
100	$226,000	$339,500	$527,000	$705,500

1) Costs include carbon steel structure coated with an epoxy paint, non-metallic trash baskets with Type 304 stainless mesh, and intermittent operation components and installation.

Table 2-39. Estimated Total Capital Costs for Traveling Screens With Fish Handling Features (Equipment and Installation)[1] (1999 Dollars)

Well Depth (ft)	Screening Basket Panel Width (ft) 2	5	10	14
10	$90,500	$132,000	$202,000	$285,000
25	$129,250	$194,000	$307,000	$453,000
50	$191,500	$287,000	$458,000	$647,000
75	$253,750	$381,500	$589,000	$831,000
100	$336,000	$477,000	$720,000	$1,010,000

1) Costs include non-metallic fish handling panels, spray systems, fish trough, housings and transitions, continuous operating features, drive unit, frame seals, engineering (averaged over 5 units), and installation. Costs do *not* include differential control system and spray wash pumps.

Tables 2-40 and 2-41 present equations that can be used to estimate costs for traveling screens at 0.5 fps and 1.0 fps, respectively. See the end of this chapter for cost curves and equations.

Table 2-40. Capital Cost Equations for Traveling Screens for Velocity of 0.5 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment: Equation[1]	Correlation Coefficient	Traveling Screens without Fish Handling Equipment: Equation[1]	Correlation Coefficient
2	$y = 6E\text{-}08x^3 - 0.0014x^2 + 28.994x + 36372$	$R^2 = 0.9992$	$y = 5E\text{-}08x^3 - 0.0013x^2 + 20.892x + 18772$	$R^2 = 0.9991$
5	$y = 1E\text{-}09x^3 - 8E\text{-}05x^2 + 12.223x + 80790$	$R^2 = 0.994$	$y = 2E\text{-}09x^3 - 0.0001x^2 + 9.7773x + 54004$	$R^2 = 0.9995$
10	$y = 5E\text{-}10x^3 - 9E\text{-}05x^2 + 12.726x + 88302$	$R^2 = 0.9931$	$y = 5E\text{-}03x^3 - 9E\text{-}05x^2 + 10.143x + 63746$	$R^2 = 0.9928$
14	$y = 6E\text{-}10x^3 - 0.0001x^2 + 15.874x + 91207$	$R^2 = 0.995$	$y = 5E\text{-}10x^3 - 0.0001x^2 + 12.467x + 65934$	$R^2 = 0.9961$

1) x is the flow in gpm y is the capital cost in dollars.

Table 2-41. Capital Cost Equations for Traveling Screens for Velocity of 1 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment: Equation[1]	Correlation Coefficient	Traveling Screens without Fish Handling Equipment: Equation[1]	Correlation Coefficient
2	$y = 8E\text{-}09x^3 - 0.0004x^2 + 15.03x + 33044$	$R^2 = 0.9909$	$y = 8E\text{-}09x^3 - 0.0004x^2 + 10.917x + 16321$	$R^2 = 0.9911$
5	$y = 2E\text{-}10x^3 - 3E\text{-}05x^2 + 6.921x + 68688$	$R^2 = 0.9948$	$y = 3E\text{-}10x^3 - 4E\text{-}05x^2 + 5.481x + 44997$	$R^2 = 0.9962$
10	$y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 6.2849x + 88783$	$R^2 = 0.9906$	$y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 5.0073x + 64193$	$R^2 = 0.9902$
14	$y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 7.1477x + 113116$	$R^2 = 0.9942$	$y = 5E\text{-}11x^3 - 2E\text{-}05x^2 + 5.6762x + 81695$	$R^2 = 0.9952$

1) x is the flow in gpm y is the capital cost in dollars.

Operation and Maintenance (O&M) Costs for Traveling Screens

O&M costs for traveling screens vary by type, size, and mode of operation of the screen. Based on discussions with industry representatives, EPA estimated annual O&M cost as a percentage of total capital cost. The O&M cost factor ranges between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen since O&M costs do not increase proportionately with screen size. Estimated annual O&M costs for traveling screens with and without fish handling features are presented in Tables 2-32 and 2-33, respectively. As noted earlier, the flow volume corresponding to each screen width and well depth combination varies based on the through screen flow velocity. These flow volumes were presented in Tables 2-42 and 2-43 for flow velocities of 1.0 fps and 0.5 fps, respectively.

Table 2-42. Estimated Annual O&M Costs for Traveling Water Screens Without Fish Handling Features (Carbon Steel - Standard Design)[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft): 2	5	10	14
10	$4560	$6545	$7650	$12,870
25	$5810	$9905	$14,040	$17,175
50	$8680	$12,270	$17,250	$23,625
75	$11,550	$16,290	$21,800	$29,575
100	$13,560	$16,975	$26,350	$35,275

1) Annual O&M costs range between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen.

Table 2-43. Estimated Annual O&M Costs for Traveling Water Screens With Fish Handling Features (Carbon Steel Structure, Non-Metallic Fish Handling Screening Panel)[1] (1999 Dollars)

Well Depth (ft)	Screen Panel Width (ft) 2	5	10	14
10	$7240	$9240	$10,100	$17,100
25	$9048	$13,580	$18,420	$22,650
50	$13,405	$17,220	$22,900	$32,350
75	$17,763	$22,890	$29,450	$41,550
100	$20,160	$23,850	$36,000	$50,500

1) Annual O&M costs range between 8 percent of total capital cost for the smallest size traveling screens with and without fish handling equipment and 5 percent for the largest traveling screen.

The tables below present O&M cost equations generated from the above tables for various screen sizes and water depths at velocities of 0.5 fps and 1 fps, respectively. The "x" value of the equation is the flow and the "y" value is the O&M cost in dollars.

Table 2-44: Annual O&M Cost Equations for Traveling Screens Velocity 0.5 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment: Equation[1]	Correlation Coefficient	Traveling Screens without Fish Handling Equipment: Equation[1]	Correlation Coefficient
2	$y = -3E\text{-}05x^2 + 1.6179x + 3739.1$	$R^2 = 0.9943$	$y = -2E\text{-}05x^2 + 1.0121x + 2392.4$	$R^2 = 0.9965$
5	$y = -1E\text{-}05x^2 + 0.8563x + 5686.3$	$R^2 = 0.9943$	$y = -7E\text{-}06x^2 + 0.6204x + 4045.7$	$R^2 = 0.9956$
10	$y = -2E\text{-}06x^2 + 0.5703x + 5864.4$	$R^2 = 0.9907$	$y = 9E\text{-}11x^3 - 1E\text{-}05x^2 + 0.8216x + 1319.5$	$R^2 = 0.9997$
14	$y = 5E\text{-}12x^3 - 1E\text{-}06x^2 + 0.4835x + 10593$	$R^2 = 0.9912$	$y = 8E\text{-}12x^3 - 2E\text{-}06x^2 + 0.3899x + 7836.7$	$R^2 = 0.9922$

1) x is the flow in gpm and y is the annual O&M cost in dollars.

Table 2-45. Annual O&M Cost Equations for Traveling Screens Velocity 1 fps

Screen Width (ft)	Traveling Screens with Fish Handling Equipment: Equation[1]	Correlation Coefficient	Traveling Screens without Fish Handling Equipment: Equation[1]	Correlation Coefficient
2	$y = -8E\text{-}06x^2 + 0.806x + 3646.7$	$R^2 = 0.982$	$y = -4E\text{-}06x^2 + 0.5035x + 2334$	$R^2 = 0.9853$
5	$y = -3E\text{-}06x^2 + 0.4585x + 5080.7$	$R^2 = 0.9954$	$y = -2E\text{-}06x^2 + 0.3312x + 3621.1$	$R^2 = 0.9963$
10	$y = -6E\text{-}07x^2 + 0.2895x + 5705.3$	$R^2 = 0.9915$	$y = 1E\text{-}11x^3 - 3E\text{-}06x^2 + 0.4047x + 1359.4$	$R^2 = 1$
14	$y = -3E\text{-}13x^3 - 4E\text{-}08x^2 + 0.2081x + 11485$	$R^2 = 0.9903$	$y = 4E\text{-}13x^3 - 3E\text{-}07x^2 + 0.1715x + 8472.1$	$R^2 = 0.9913$

1) x is the flow in gpm and y is the annual O&M cost in dollars.

Adding fish baskets to existing traveling screens

Capital Costs

Table 2-46 presents estimated costs of fish handling equipment without installation costs. These estimated costs represent the difference between costs for equipment with fish handling features (Table 2-33) and costs for equipment without fish handling features (Table 2-32), plus a 20 percent add-on for upgrading existing equipment (mainly to convert traveling screens from intermittent operation to continuous operation).[9] These costs would be used to estimate equipment capital costs for upgrading an existing traveling water screen to add fish protection and fish return equipment.

Table 2-46. Estimated Capital Costs of Fish Handling Equipment (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft): 2	5	10	14
10	$40,200	$46,200	$58,800	$84,600
25	$55,500	$63,000	$87,600	$131,400
50	$81,000	$99,000	$135,600	$209,400
75	$106,500	$132,000	$183,600	$287,400
100	$132,000	$165,000	$231,600	$365,400

Source: Vendor estimates.

Installation of Fish Handling Features to Existing Traveling Screens

As stated earlier, the basic equipment cost of fish handling features (presented in Table 2-46) is calculated based on the difference in cost between screens with and without fish handling equipment, plus a cost factor of 20 percent for upgrading the existing system from intermittent to continuous operation. Although retrofitting existing screens with fish handling

[9]This 20 percent additional cost for upgrades to existing equipment was included based on recommendations from one of the equipment vendors supplying cost data for this research effort.

equipment will require upgrading some mechanical equipment, installing fish handling equipment generally will not require the use of a costly barge that is equipped with a crane and requires a minimum number of crew to operate it. EPA assumed that costs are 75 percent of the underwater installation cost (Table 2-36) for a traveling screen (based on BPJ). Table 2-47 shows total estimated costs (equipment and installation) for adding fish handling equipment to an existing traveling screen.

Table 2-47. Estimated Capital Costs of Fish Handling Equipment and Installation[1] (1999 Dollars)

Well Depth (ft)	Basket Screening Panel Width (ft)			
	2	5	10	14
10	$46,200	$55,575	$71,550	$100,725
25	$68,250	$79,125	$107,100	$154,275
50	$100,500	$121,875	$161,850	$239,025
75	$132,750	$161,625	$216,600	$323,775
100	$165,000	$201,375	$271,350	$408,525

1) Installation portion of the costs estimated as 75 percent of the *underwater* installation cost for installing a traveling water screen.

The additional O&M costs due to the installation of fish baskets on existing traveling screens can be calculated by subtracting the O&M costs for basic traveling screens from the O&M costs for traveling screens with fish baskets. See the end of this chapter for cost curves and equations.

2.10 ADDITIONAL COST CONSIDERATIONS

To account for other minor cost elements, EPA estimates that 5 percent may need to be added to the total cost for each alteration. Minor cost elements include:

- Permanent buoys for shallow waters to warn fishing boats and other boats against dropping anchor over the pipes. Temporary buoys and warning signs during construction.
- Additional permit costs. Permit costs may increase because of the trenching and dredging for pipe installation.
- Facility replanning/redesign costs may be incurred if the facility is far enough along in the facility planning and development process. This cost would likely be minimal to negligible for most of the alterations discussed above, but could be much higher for switching a facility to a recirculating cooling system.
- Monitoring costs (e.g., to test for contaminated sediments).

As noted earlier, if the intake structure installation involves disturbance of contaminated sediments, the permitting authority may require special construction procedures, including hauling the sediments to an appropriate disposal facility offsite. This may increase the cost of the project by more than two to three times the original cost estimate.

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In addition to the references listed below, EPA recognizes contributions from the following individuals and organizations: Russel Bellman and Brian Julius, Acting Chief, Gulf Coast Branch NOAA Damage Assessment Center, Silver Spring, MD, of the National Oceanic and Atmospheric Administration; Adnan Alsaffar, Arman Sanver, and John Gantnier, Bechtel Power Corporation, Fredrick, MD; Gary R. Mirsky Vice President, Hamon Cooling Towers, Somerville, NJ; Jim Prillaman, Prillaman Cooling Towers, Richmond, VA; Ken Campbell GEA Power Systems, Denver, CO and David Sanderlin, GEA Power Systems, San Diego, CA; Michael D. Quick, Manager - Marketing / Communications, U.S. Filter - Envirex Products, Waukesha, WI; Trent T. Gathright, Fish Handling Band Screen Specialist, Marketing Manager, Brackett Geiger USA, Inc., Houston, TX; Richard J. Sommers, U.S. Filter Intake Systems, Chalfont, PA; Ken McKay, VP Sales/Marketing, USF Intake Products; and Larry Sloan, District Representative, Sloan Equipment Sales Co.,Inc., Owings Mills, MD.

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